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ELECTRICAL ENGINEERING

FOR ELECTRIC LIGHT ARTIZANS AND STUDENTS

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,, 202 and 203	. . .	,,

ELECTRICAL ENGINEERING

CHAPTER I.

CURRENT—POTENTIAL—CONDUCTORS—INSULATORS.

WHEN a stick of sealing-wax is rubbed with a piece of dry fur or flannel, the wax acquires the power of attracting to itself any light substances that may be in its vicinity. By taking suitable precautions a like power can be detected in the fur or flannel. Similar phenomena can also be produced by the rubbing together of other substances, such as glass and silk, india-rubber and silk, brown paper and a bristle clothes-brush, &c. A body which exhibits this power of attraction is said to be endowed or charged with electricity, or to be electrified.

But there are two electrical states, and this can be easily proved, for if by means of a foot or so of silk ribbon we suspend the electrified sealing-wax and bring near it another electrified stick of sealing-wax, repulsion ensues, that is to say, the suspended rod recedes from the approaching one. On the other hand, if certain necessary precautions have been taken to prevent the neutralisation or escape of the electricity that was generated on the fur or flannel rubber, it will be seen, on bringing it near the suspended sealing-wax, that attraction takes place. A similar result would follow if a warm glass rod were rubbed with a piece of dry silk and then brought near the sealing-wax. On suspending, however, the electrified glass and bringing the electrified fur near it, repulsion would take place. It is manifest, then, that as electrified glass attracts electrified sealing-wax, but is repelled by or repels electri-

the amount of electricity developed by rubbin
say the sealing-wax and the fur—together bea
to the amount of actual friction to which the b
for what is really essential in order to obtain t
degree of electrification is to bring every portio
into intimate contact with every superficial p
and when that is done, no extra amount of r
any further degree of electrification.

Speaking generally, then, it may be said t
bodies are rubbed together electricity is pro
frequently happens that the amount is so sm
detection very difficult. If, however, delicate a
will not pause here to describe, is employed,
can be indicated. In fact, if a piece of zi
copper are simply placed in contact the feeb
tricity then developed can easily be rendere
same pieces of metal are placed in saline or
similar result follows, although in this case the w
an important factor in determining the resul
The end of the zinc outside the liquid will b
properties similar to those of the sealing-wax
rubbed with fur. It is, therefore, said to be ne
The copper, on the other hand, will have an ele
to that of the fur itself, or of the glass which

negative, [illegible] character of the [illegible]

It may be [illegible] of force is [illegible] extent [illegible] universal [illegible] is to say, [illegible] established [illegible] possible. [illegible] immersed [illegible] ferent degrees. [illegible] or, as it is [illegible] accomplished [illegible] this is [illegible] be called an [illegible] piece of [illegible] due to this [illegible] the two [illegible] tary rush of [illegible] This phenomenon [illegible] and it [illegible] metal [illegible]

This brief [illegible] it is to restore the [illegible] of chemical changes [illegible] other things a [illegible] into what is called a [illegible] cause in their [illegible] which is followed [illegible] that by a further [illegible] one another in exceedingly rapid [illegible] that it is a matter of absolute [illegible] separately, and we have consequently [illegible] what is known as a continuous current [illegible]

A little reflection will make it evident [illegible] the line of experiment and deductions here indicated the single and double fluid theories of electricity are [illegible] not simply for the sake of disregarding them but [illegible]

are unnecessary and involve considerations and concessions which are not warranted by the circumstances. In point of fact, electricity is not a fluid at all, and only in a few of its attributes is it at all comparable to a fluid.

Let us rather consider electricity to be a condition into which material substances are thrown, and that *all* such substances partake more or less of this condition, just as we say that all bodies are heated, although to varying degrees, and that in virtue of this heat their particles are set into more or less rapid vibration.

Moreover, as in the case of a heated body, there is a region surrounding an electrified body in which the force due to the tendency to produce electrical equilibrium can be made evident. This is shown by the fact already referred to that two bodies in a similar electrical state repel one another, while others in different electrical states attract. It is inconceivable that such an effect as the imparting of motion to a mass of matter could be produced without the aid of some medium capable of transmitting the force. What this medium actually is is a matter of doubt, and we cannot experimentally determine the question. So also is the mode or method of transmission. Under such circumstances it becomes convenient to picture to ourselves the propagation by means of *lines of force*, travelling through an infinitely elastic, imponderable medium, or substance, as it is sometimes called, which is assumed to pervade all matter and all space, and which is known as 'ether.' Granted that these lines of force may have no actual existence, the conception is, nevertheless, exceedingly useful, and facilitates an accurate estimation of the way in which electrical phenomena are set up, so much so, that the idea imperceptibly grows upon the student, and to him the lines of force become endowed with a definite meaning.

There are three features about these lines of force to which we may now draw attention. In the first place, their assumed position indicates the path along which the action takes place; secondly, their direction indicates the direction in which the force is transmitted; and, thirdly, their density, or the number occupying a given space, measures the strength or magnitude of the force. Having given to these lines of force position, direction, and density, we can predict the result which should follow in any

given electrical field. For the action is always as if the lines of force endeavour to coincide in direction, and then to shorten themselves, the magnitude of the action being simply dependent upon the density of the lines.

In the case of an electrified sphere suspended somewhere in space and remote from every disturbing element, the lines of force would be radial and equidistant in position, their density would depend upon the degree of the electrification or the quantity of the charge, while their direction, that is, radially inwards or radially outwards, would depend upon whether the charge were negative or positive.

Let us assume a positively charged sphere to be suspended, with its lines of force directed outwards, and a second sphere, negatively charged, with its inwardly directed lines of force, to be brought into the vicinity of the first sphere; it will be evident that many of the lines of force of the two spheres will bend or turn round and concentrate themselves within the space intervening between the spheres. The lines of force will now be similar in direction, and, owing to the shortening tendency above referred to, attraction results.

The attraction, presuming it to be sufficiently strong, will impart motion to one or both of the spheres, or, in other words, work will be performed. Now this capacity for doing work arises solely from the electrification, and the quantity of work performed is proportional to the degree of electrification. But 'capacity for doing work' and 'potential' are convertible terms—that is to say, anything which possesses the capacity for doing work is said to have a certain potential, consequently the degree of electrification of any body is known as its potential. We have previously said that the tendency to produce, between two electrified points or bodies, a state of electrical equilibrium, is proportional to the difference of their degrees of electrification. In technical language this means proportional to their difference of electrical potentials. Therefore, in the case of the zinc and copper plates immersed in acidulated water, the flow of electricity from the exposed end of the copper to the exposed end of the zinc is correctly described as being due to a difference of potential between those ends.

If the student has grasped what has already been said, he will be able to readily apply the doctrine of potential to special cases; for example, it will be evident that no two parts of the same body (providing it is one that can transmit or propagate the flow of electricity) can remain for any length of time at different potentials, for the moment a difference of potential is established an electrical stress is set up, and the flow of electricity follows as a necessary or natural consequence. On the other hand, where there is no difference of potential there can be no flow of electricity. So that we come to these conclusions—viz. that electricity always flows between two bodies which are at different potentials; that it flows from the body possessing the higher to that possessing the lower potential; that in the case of the 'current' maintained by the 'simple cell,' composed of zinc and copper plates dipping into acidulated water and described in a previous page, we had a difference of potential established on the zinc and copper extremities; that on joining these extremities together there was a flow of electricity to produce equilibrium; that this, by means of the chemical changes, re established a potential difference; and that these actions and reactions, being alternated with infinite rapidity, appear to us as a continuous current.

We may, therefore, define a 'current' as the expression of an effort ever being made to establish electrical equilibrium between two points which are ever being electrified to different potentials. Neither of these objects is attained—that is to say, a difference of potential is never permanently established on the one hand, and, on the other, equilibrium it is impossible to maintain.

Let us further consider the case of the simple cell, the zinc and copper of which, however, instead of being joined together, are each connected to long pieces of wire, whose other or free extremities are inserted in the earth at different places. It used to be the general assumption that in this case the current would flow from the copper plate to the earth, and through the earth to the other wire, up which it would pass and so return by the zinc to the battery. But anything more unreasonable than such an hypothesis it is really impossible to conceive. To demonstrate this we need only take into consideration the state of affairs at the Central Telegraph Office in London, where there are 1,000

different circuits or lines, one end of each battery being joined to the same earth plate under the office, the other ends being joined to the respective lines, which in their turn are joined to earth plates at the distant ends. Viewed in its real aspect, this 'earth-return' theory compels the assumption that the 1,000 currents which go to earth at as many different places some at Newcastle, some at Liverpool, others at Cardiff, Yarmouth, &c., others, again, only a few hundred yards away in several of the City thoroughfares—all return through the earth to the earth plate or connection under the Central Office, where each individual current has to pass the other 999 currents travelling through the plate, and single out the particular wire joined to the particular battery from the other end of which it emanated, and is not satisfied or has not completed its work until it thus gets safely home again. It will readily be seen that, if such were actually the state of affairs, the laws above stated, that electricity only flows under a difference of potential and always flows when there is that difference, would be nullified.

Like everything else in the universe, the earth itself is always more or less electrified, and, as a consequence, it is always at a certain potential. It will therefore be seen that, were a body which had been electrified to a higher potential than the earth to be connected with the earth, a flow of electricity would take place passing from that body to the earth, so that both the body and earth assume the same potential, and it may be mentioned that the passage of this flow could be easily observed by the introduction of certain apparatus. On the other hand, were a body to be electrified to a potential lower than that of the earth and to be connected with it, a flow of electricity would be determined between the earth and the body, and the passage of this electricity could also be rendered evident. Consequently, when copper and zinc strips are immersed in acidulated water and the exposed ends become electrified, the one to a higher and the other to a lower potential than the earth, the connection of those extremities with the earth causes a flow of electricity from the plate of higher potential to the earth, and from the earth to the plate of lower potential. These flows will be equivalent to joining the plates directly together and so releasing the electrical stress.

Thus is it with every battery: the potential of the earth is above that of one end of the battery and below that of the other end. There is then no need for a current to flow between the two earth-connections, and the assumption of such a state of affairs is quite gratuitous. It must not, however, be supposed that the flow of electricity from or to the earth can sensibly affect its charge or potential, the terrestrial charge as a whole being so enormous as to make any other charge or potential incomparably feeble and insignificant. To make this clearer we will employ an analogy. Let us suppose that we have two tanks containing water, the bottom of one being placed ten feet above the level of the ocean, and the other, which we will suppose to be very deep, immersed until the surface of the contained water is ten feet below the ocean level. If now we suppose holes to be made in the bottoms of the tanks, all the water will flow out of the higher tank into the sea below, while water will flow up into the lower one until the ocean level is reached. But of course no one would contend that these changes would make any difference in the level of the surrounding waters, even if more water were received from the higher tank than was given to the lower, and what is true in this case is equally true in the case of electricity. In fact, the earth is a body whose capacity for electricity, so far as we are concerned, is infinite, and nothing that we can do can alter its charge. The man who would assert that when he joins one end of his battery to earth, say, at London, and the other end to earth, say, at Aberdeen, and that in consequence a current flows through the earth from one connection to the other, asserts, in fact, although he may not know the significance of his contention, that he places these two points in London and Aberdeen at different electrical potentials. He might as reasonably contend that if he turns on his water-tap into the Thames at London and digs a hole in the bank of the river at Windsor, he sets up a difference of level between the two places, and causes the water which he pours in at London to travel up against the stream and fall out at Windsor.

We come now to a real difficulty—a solution of which is improbable, although it is, perhaps, in the future not impossible—and that is, to be able to say with certainty in which direction a

current really travels, or, in other words, to declare which of two differently electrified bodies has the higher, and which the lower potential. All we can say with any certainty is that there is a difference of potential, and that therefore the current flows from the point of higher to that of lower potential. It is usual to assume, in the present incomplete and imperfect state of our knowledge concerning the nature and propagation of electricity, that the electric state which we know as positive has a higher potential than that state which we know as negative, whence we say, or assume, that electricity flows *from* a positively electrified *to* a negatively electrified body. And we will in this work follow this assumption, true or otherwise, as it involves no sacrifice of principles, notwithstanding the fact that experiments have been performed which tend to show that that state which we call negative is really of higher potential than that which we call positive.

Reference has several times been made to the use of wire as a means of connection between two oppositely electrified bodies, or between two bodies at different potentials. Were we desirous of transmitting mechanical instead of electrical energy, a hempen or silken cord would answer equally well, if due provision had been made that the cord should have the requisite mechanical strength or tenacity to transmit the energy without fracture. But tenacity is not the necessary attribute for a body to possess in order that electricity may be readily propagated through it. All substances admit of this transmission, although to very varying degrees. A piece of copper wire offers greater facilities than a piece of iron wire of similar dimensions, which in turn offers greater facilities than a similar piece of German-silver wire. But the metals one and all are enormously superior in this respect to the great bulk of non metallic substances. On the other hand, every substance, whatever its nature, offers a greater or less amount of resistance to the transmission of electricity. Bodies which offer little resistance to the electric flow are said to be good conductors, while those which offer considerable resistance are said to be bad conductors or insulators. To the former class belong the metals, carbon, ordinary water, &c., the latter class including such substances as glass, air, sulphur, resin, india rubber, and ebonite. Between these two classes are many substances which might

the lower until electrical equilibrium between
obtained. And a similar result follows if we
together by a piece of wire ; while if they have
other bad conducting substance separating them,
flow at all, or only a very feeble one. If the pat
made longer, or more difficult, say by the interpos
or poorer conductor, it naturally follows that th
taken for equilibrium to be restored is lengthened
restoration, that is, the strength of the current, is
potential difference and the quantity of electrici
the same in the two cases, the energy expended
restore equilibrium is the same.

The result, then, of interposing a substance
ducting power, or, what amounts to the same
resistance, between two bodies having a potential
reduce the strength of the flow or current passing
the other. We can find a very simple analog
suppose two tanks of water at different heights or
the other. So long as the bottom of the higher
resistance to the flow of water from it to the ot
infinite, but if we interpose a relatively bad condu
in the form of a very small pipe or tube between
tanks, there will be a correspondingly weak or fee
from the higher to the lower tank. If we inc
bore of the pipe, the conducting power will be

most infinitely small, or, in other words, by varying the amount resistance which is here shown to be the converse or reciprocal conductivity, we can, in a corresponding value, vary the strength the current.

To summarise our observations on the question of resistance, e may say that if we electrify two bodies, connected only by the r, to different potentials, we subject the intervening air to a ecies of stress. If we very considerably increase the potential, e air being no longer able to sustain the stress, a discharge or electric flow ensues. A similar result can be achieved, without creasing the potential difference, by reducing the distance etween the electrified bodies, or by bridging over the air space ith a piece of wire or other good conductor. In either case the bility to sustain the stress is reduced, and we call this ability to stain the stress resistance. The more resistance we insert etween the electrified points or bodies, the more do we thereby duce or prevent the flow of electricity.

CHAPTER II.

PRACTICAL UNITS—OHM'S LAW—FUNDAMENTAL UNITS.

In dealing, in the previous chapter, with the general attributes of electricity, the only degree of comparison arrived at was to say that one electrification, resistance, or current was greater or less than another. And to a somewhat considerable extent this was, until within the last few years, deemed sufficient. It is, however, now essential that more precision in comparing or measuring forces and their properties and effects should be obtained. Measurement is, in fact, the most important branch of electrical science, as, indeed, it is of every other physical science.

Instead of simply saying that one lump of iron is heavier or weightier than another, it is usual to say by how much they differ. Thus one lump may have a mass of ten pounds, and another a mass of twenty pounds. The latter is therefore ten pounds heavier than the former. We have here introduced a unit of measurement, viz. the pound, or unit of mass. Similarly, the inch or foot may be used as a unit of length, the second as a unit of time, the pint as a unit of capacity, the sovereign as a unit of coinage, and so on. These units are all such as everybody can readily appreciate. They are so frequently employed that no mental effort is required to understand what is meant when any one of them is mentioned.

In dealing with electricity the first thing we wish to measure is naturally the amount of the electrical difference between two bodies which causes an electrical stress and which may result in a current of electricity. But we are confronted with two difficulties. The first is that by none of the everyday units—by no unit employed for any other purpose—are we able to indicate exactly the electric potential in a body. Moreover, electricity being but a condition of matter, and not matter itself, it is impossible to

measure it directly. We can only measure it by its effect upon material substances. In the next place, inasmuch as it is impossible to obtain or even to conceive of a body altogether devoid of electrification (although it is not always perceptible), it is impossible to fix on an absolute zero potential, and measure potentials from that point: in just the same way that it is impossible to have a zero level, some arbitrary point such as the sea level at high tide having to be employed if we wish to measure the relative height of two or more points. It is, consequently, necessary to look elsewhere for a starting point, and to fix on a convenient arbitrary potential zero. We take as a zero the potential of the earth's surface, and bodies which are said to be positively electrified are at a higher potential than the earth, while negatively electrified bodies are at a lower potential. Positive and negative potentials may therefore be said to correspond to height and depth in their relation to the sea-level. Inasmuch, however, as we are unable to detect any potential at all unless we take two points or bodies whose potentials are different, the measurement of potential itself again presents difficulties. On the other hand, when we are called upon to measure the potentials of two bodies, what we really desire to know is the difference between those potentials; or, if we call the potential of one body P, and that of the other P_1, we want to know the value of $P - P_1$; for, after all, it is this difference of potential that determines the flow of electricity. This difference of potential is known as electro motive force, which is frequently contracted into the initials E.M.F., or, shorter still, into E. only. It is this electro motive force, then, that we desire to measure, and the practical unit by which it is measured is known as the 'volt.' We will, for the present, rest satisfied with the simple statement that the volt is approximately equal to, although actually a fraction less than, the electro-motive force of a single Daniell cell. (See Chapter III.)

Reference was made in the previous chapter to 'resistance,' and it was described as the converse of conductivity, which again we described as the ability of a body to transmit a current of electricity. It is easy to show that resistance may be expressed as a ratio—the ratio of electro motive force to current—and many authorities insist that it should always be regarded thus. It may also be

teaches us that force is indestructible, and it
that if energy has to be expended in impelling
against a greater or less amount of resistance
that energy must be developed in some other
form is usually heat ; or, in other words, when
certain amount of resistance to the passage of
produced, the actual amount of heat being an
of the energy expended in overcoming the resis
therefore directly as that resistance. Consequ
two conductors, the resistance of one of which
other, and if we send currents of equal stren
wires, twice as much heat will be developed i
the higher resistance as will be developed in tha
resistance. We shall have occasion to deal
more fully in a future chapter, but we may ad
wish to perform work at any point by means of
conducted by a wire to that point, we must kee
that wire down to the lowest practical limit, bec
of the energy frittered away in heating the co
much less energy available for the particular w
the current to perform. It is apparent, then,
unit by which we shall be able to compare
various substances, and the unit selected is call
was decided by an International Congress of

which determined the value of this unit also decided that it should be known as the 'legal' ohm. A millionth part of this unit is called a microhm, and one million ohms a megohm.

There have, in the past, been an almost unlimited number of units, more or less crude and unreliable; for it must be borne in mind that for a unit to be of any real value it must be permanent or durable, it must be capable of confirmation, and its derivation must be well known and invariable. One of the earlier units of resistance was that offered by a mile of the then best procurable iron wire of a certain gauge or diameter. The indefiniteness of such a unit may be conceived when it is called to mind that even now no two samples of the same wire will offer the same resistance; and still more so was this true a few years ago, when the quality of iron wire as a conductor was vastly inferior compared with what it now is, both as regards its actual resistance and its uniformity.

The only other unit which we need consider is that known as the B.A., or British Association Unit. It was determined in London in 1863 by a committee appointed for the purpose by the British Association, and the method of determination then adopted was the basis upon which the Paris or legal ohm was afterwards calculated. These units are both based on what is called the C.G.S. system (p. 40), the Paris unit being really a correction of the B.A. unit. The practical standard of the former has, however, a great advantage over that of the latter, which consisted of the resistance of a certain length of wire carefully preserved in London. This was, of course, rarely used, and duplicates of the standard had to be employed for comparing or standardising other resistances. The legal ohm is manifestly capable of being reproduced more easily, and it is this fact which imparts to it its chief value. The B.A. unit is a fraction smaller than the Paris ohm, the actual proportion being 0·986 to 1·0. If it were possible at the present day to universally adopt a common unit, it would certainly be a great advantage, for then everybody would know what was meant when anybody else mentioned any particular resistance. But prior to 1884 a vast quantity of electrical apparatus and machinery was in use, and everything in England and some other countries was measured by the B.A. unit,

while the measurements employed on the Continent were for the most part referrible to the Siemens unit, which was the resistance of a column of mercury 1 metre (or 39·37 inches) long, the other details as to its size, temperature, and pressure being the same as those employed in devising the legal ohm. As it was, the various administrations and authorities were placed in a most unpleasant dilemma. If they re-standardised and re-marked all their existing apparatus they would have had to incur enormous expense, while if they continued the use of their existing standards they would be perpetuating an inconvenience which they had called the Congress together to remove. In the majority of cases, questions of finance compelled them to adopt the latter alternative, so that with us, most telegraph apparatus continues to be measured by the B.A. unit, while the apparatus employed in the newer industries, such as electric lighting, is measured by the legal ohm. Accordingly, in this work we shall endeavour to keep the latter in view.

The student will frequently come across the expression 'specific resistance,' and it is a most important term. It may be defined as the resistance of any particular substance as compared with the resistance of a piece of some other conductor, such as silver, of similar dimensions, the test being made under similar conditions. It is a matter of great convenience that different bodies vary in their relative or specific resistances, for there are times when we want the lowest possible resistance, while at other times we require a large measure of resistance, more particularly when we desire to prevent an electric discharge, to prevent the flow of an electric current, or to prevent electricity leaking from one body to another. Appended is a table based upon that of Dr. Matthiessen which shows the relative resistance of a number of metals frequently met with, and as the variation of the temperature of a body varies its electrical resistance, all the tests have been taken at a constant temperature, viz. that of freezing point, or the necessary corrections made to correspond to that temperature.

An alloy of copper, nickel, and zinc (the usual constituents of German silver), combined with 1 or 2 per cent. of tungsten, was introduced a few years ago under the name of platinoid. It is found that the addition of tungsten imparts greater density to alloys

TABLE SHOWING RELATIVE RESISTANCES [illegible]
AT 0° C. [illegible]

Name of Metal	Relative Resistance	[illegible]	[illegible]	[illegible]	
				[illegible]	[illegible]
Silver, annealed . .	1.000	[illegible]	[illegible]	[illegible]	[illegible]
Copper, annealed . .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Silver, hard drawn . .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Copper, hard drawn .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gold, annealed . .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gold, hard drawn . .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Aluminium, annealed .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Zinc, pressed . . .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Platinum, annealed .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Iron, annealed . .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lead, pressed . .	[illegible]	—	[illegible]	[illegible]	[illegible]
German silver, hard or annealed . . .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Platinum, silver alloy (⅓ platinum ⅔ silver) hard or annealed . .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mercury . . .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]nd reduces any tendency [illegible]
[illegible]carcely distinguishable in [illegible]
[illegible]metre offers a resistance [illegible]
[illegible]o that its resistance is about [illegible]
[illegible]ilver. As, however, alloys always [illegible]
[illegible]osition, a definite resistance [illegible]
[illegible]ommercial variety, and calculations [illegible]
[illegible]ccepted as actually true of [illegible]
[illegible]oid, when drawn hard, is, like copper [illegible]
[illegible]udden cooling.

The admixture of even a minute [illegible]
[illegible]ery considerably reduces the [illegible]
[illegible]sistance of a metal. A very [illegible]
[illegible]n alloy of two or more metals is [illegible]
[illegible]resistance of the alloy will always be found [illegible]
[illegible]ither of its constituents. Purity [illegible]
[illegible]nd absolute uniformity in [illegible] of alloy, [illegible]
German silver, is, therefore, [illegible]

(*All the wires were anneal*…

Pure copper	
Lake Superior, native, not fused . .	
Ditto, fused, as it comes in commerce .	
Burra Burra	
Best selected	
Bright copper wire	
Tough copper	
Demidoff	
Rio Tinto	

Or, again, if the relative conductivity of pu… as 100, then that of copper mixed with 1·6 per… silver will be only 65; while the conductivity o… 1·2 per cent. in volume of gold will be 59 when… is taken as 100.

A highly interesting phenomenon is the wor… a variation in temperature produces upon th… various substances through which a current ma… would be less surprising were it general or w… uniform in all bodies, but the great feature to… while in the case of metals the resistance of a c… increases with an exaltation in temperature, the … a decrease in resistance under similar circumst…

possible the same value at all temperatures. It may be observed that the insulating coatings of the wires in the telegraph cables laid in such waters as the Indian Ocean show a marked decrease in their insulating properties after submergence, consequent upon the fact that the water is several degrees warmer than that in the tanks in which the standardising tests were made. The accompanying table, showing the percentage variation in the resistance of various bodies between the temperature of freezing water and that of boiling water, should prove eminently interesting. It is certainly useful and important.

Name of Metal	Conducting power at 0° C. Silver = 100	Percentage fall of conducting power between 0° and 100° C.
Pure iron	16·81	39·2
Pure thallium	9·16	31·4
Other pure metals in a solid state	—	29·3
Gold with 15 p.c. iron	2·76	27·9
Proof gold	72·55	26·4
Standard silver	80·63	23·2
Gun metal (Austrian)	27·08	18·3
Copper with 25 p.c. platinum	22·08	11·5
Silver with 5 p.c. platinum	31·64	11·3
Silver with 9·8 p.c. platinum	18·04	7·1
Copper with 9·7 p.c. tin	12·19	6·6
Gold silver alloy	15·03	6·5
Platinum with 33·4 p.c. iridium	4·54	5·9
German silver	7·80	4·4
Gold with 4·7 p.c. iron	2·37	3·8
Silver with 25 p.c. palladium	8·52	3·4
Silver with 33·4 p.c. platinum	6·70	3·1
Platinoid	—	2·09

As may have been gathered from what has already been said, when we increase the length of a conductor we invariably increase its resistance. This follows as a matter of course from the fact that if we urge a certain current through a wire of increased length, we give it more work to do, necessitating, consequently, a greater expenditure of energy in precisely the same way that a railway engine would consume more coal in taking a train a distance of 200 miles than it would consume in taking it only half that distance. The resistance of a conductor of uniform material and thickness or cross-section varies directly as its length—that is to say, if we vary the length of the conductor we vary its

resistance at exactly the same rate, or, in fewer words, resistanc varies directly as the length of the conductor. If a mile of wi of a certain gauge offers a resistance of ten ohms, two miles of th same wire would offer twenty ohms.

The effect of increasing the size or sectional area of a con ductor is to increase its conductivity and, consequently, to diminis its resistance, in exactly the same way that increasing the diamete of a pipe increases the amount of gas or water that can be passed through it. The resistance of a conductor varies inversely as it sectional area. That is, if we have two conductors, such as tw specimens of copper wire, drawn from the same bar, the amoun of resistance which the wires will offer depends upon the size o the wires or on the area of the ends exposed on cleanly cuttin them at right angles to their length—that is to say, upon th amount of metal through which the current can flow. Most wir are round, so that the section is a circle, and it becomes necessar to understand the method of comparing the areas of circles. Th area of a circle varies as the square of its diameter ; for exampl if we have two circles, one having a diameter of one-tenth of a inch and the other of two-tenths of an inch, their areas or th spaces they enclose will not be in the proportion 1 : 2, but as th squares of those figures, viz. 1 : 4, so that one wire which is twic the diameter of another, other things being the same, only offe one quarter of the resistance offered by the thin wire. While if w treble the diameter of the wire, or make it three-tenths of an inc the resistance will be only one ninth of that of the thinnest wir As a matter of fact, the thickest of these three wires will weig exactly nine times as much as the thinnest, there being nine time as much metal in it. We may, therefore, state our law in oth words by saying that the resistance of wires uniform in a particulars excepting thickness varies inversely as their weigh Thus, if a mile of copper wire weighs 100 lbs. and has a re sistance of 9 ohms and an equal length of similar copper wi weighs 150 lbs. the resistance of the latter will be 6 ohms. Agai the specific resistances of iron and copper are approximately a 6 to 1. If, now, a mile of iron wire, 0·240 of an inch in diamete has a resistance of 5 ohms, and it is thought for certain reason desirable to substitute a mile of copper wire having the sam

ge, we should have to use wire weighing one sixth the of, or whose sectional area would be one sixth of, that of a rire 0·240 of an inch in diameter, because the resistance e of the latter would be only five sixths of an ohm. The thickness could be ascertained by rule of three, for if for the required diameter,

$$6 : 1 :: (0{\cdot}240)^2 : x^2,$$

ich we find $x^2 = 0{\cdot}0096$. Therefore x, or the required , is equal to the square root of 0·0096, or 0·098 of an rly.

nductor offers to the passage of electricity at equal tem- a constant resistance which is altogether independent the electro-motive force or of the strength of the current. o say, a wire which offers 10 ohms to the passage of a rrent, offers precisely the same resistance to a powerful xcept in so far as an increase in the strength of the current a corresponding increase in the temperature of the wire, increased temperature causes a proportionately increased e, as already pointed out.

ome now to the consideration of the laws which deter- strength of a current and of the relationship subsisting strength and the other attributes of an electric current. relationship can, perhaps, be best understood by the aid le. Let us suppose two tanks, one very high up, say four hundred feet above the ground, the other raised only t. Let both tanks contain the same quantity of water, oth of them be supplied with pipes, the one for the upper ng, however, very much smaller in diameter than that for r. On turning the taps the water from the upper tank, small in quantity, will issue forth with much greater n that from the lower tank, although the quantity or rate rom the lower tank may considerably exceed that from r tank. In other words, the pressure in the long small much greater than in the short but large one, while the of water delivered by the former is considerably less than vered by the latter. Pressure in a column of water nds with the electro-motive force of a battery, while the

volume or quantity of water flowing through the pipe corres- to current strength. But to pursue the analogy still fa if the upper tank be raised sufficiently high, the greater pr so obtained will augment the velocity of the water, and the tanks will be emptied in the same time. There are two th then, that govern the quantity of water delivered or the delivery—viz. the pressure, and the size of the pipe, which corresponds in electrical considerations with the size of the ductor and consequently with the resistance.

By current strength is meant, therefore, the rate of flow of tricity, and it is measured by the quantity of electricity pa any point in a circuit, during a given time. It corresponds t rate of delivery of gas or water by a pipe. In a simple circuit pends upon two things, the electro motive force of the generat battery and the resistance of the whole circuit, which comprise wire and apparatus as well as the battery itself. The practical u current strength or rate of delivery is called the ampere, and is amount of current which is urged through a circuit of one ohm tance by an electro motive force of one volt. If this current is m tained for one second, one unit of electrical *quantity* is delivered, this unit is called the coulomb. If a current of half an am flows for two seconds, the quantity of electricity delivered is one coulomb. So also is it if a current of two amperes flo half a second, so that in every case the rate of flow, or cu strength in amperes multiplied into the time in seconds giv the total quantity of electricity or the number of coulombs. if Q represents the quantity of electricity in coulombs, C the cu strength in amperes, and t the time in seconds,

$$Q = C \times t.$$

As the quantity of electricity delivered is rarely requi be known, but rather the rate of delivery or flowing, w deal more fully with the method of ascertaining this rate order that this may be more readily understood, we will at proceed to the discussion of 'Ohm's Law,' which declare *the current strength varies directly as the electro-motive force inversely as the resistance.* This law may be represented by simple equation—

[redacted]

$$\frac{\text{Electro-motive force}}{\text{Resistance}} = \text{current strength},$$

or,

$$\frac{E}{R} = C.$$

As an example of the relation which the units bear to each other we may take the simple case of a battery having an electro-motive force of one volt and sending a current through a circuit whose total resistance is one ohm. The current strength will then be one ampere, thus:—

$$\frac{1 \text{ volt}}{1 \text{ ohm}} = 1 \text{ ampere},$$

and if this current is maintained for one second, one coulomb of electricity will have passed. By doubling the resistance, we get

$$\frac{1 \text{ volt}}{2 \text{ ohms}} = 0{\cdot}5 \text{ ampere}.$$

Similarly, by doubling the electro-motive force we get, with unit resistance,

$$\frac{2 \text{ volts}}{1 \text{ ohm}} = 2 \text{ amperes}.$$

A little reflection will make evident the subsidiary law that *the current strength is the same in all parts of the circuit* and does not in any sense vary in different parts of the same circuit. The current strength can easily be supposed to be uniform in a uniform conductor, but if we make up a circuit with wires of different degrees of conductivity, or if we interpose any liquid conductor, the same law holds good, just as would be the case if we were to urge a current of water through a pipe of variable diameter. [illegible] manifest that if a gallon of water enters the pipe in a [illegible] the same volume must pass out in the same time, [illegible] pipe to have been already full, and the same volume [illegible] every point in the pipe in the same interval of time [illegible] the thinner or smaller portions of the pipe the [illegible] faster and generates a little more heat by friction [illegible] of the pipe than in the larger sections of it. This [illegible] also holds good with regard to electricity, the thinner [illegible]

poorer conductor will be more highly heated than the thicker or better conductor. It is this fact that makes electric lighting by incandescent lamps possible. It is doubtful whether in the whole range or history of electrical science a law has ever been enunciated so full of truth and of such truly immense importance as that discovered by George Simon Ohm, and we shall find frequent need to refer to it in the succeeding chapters.

For the benefit of those, and our experience teaches us that they are very numerous, who do not understand the full meaning of a simple equation, we may say that if

$$\frac{E}{R} = C, \text{ then } \frac{E}{C} = R, \text{ and}$$

$$E = RC \text{ (or } R \times C\text{)}.$$

So that, if, of these three quantities, we are told two, we can always readily calculate the third. Thus, with a current of two amperes and an electro-motive force of 10 volts, the resistance will be

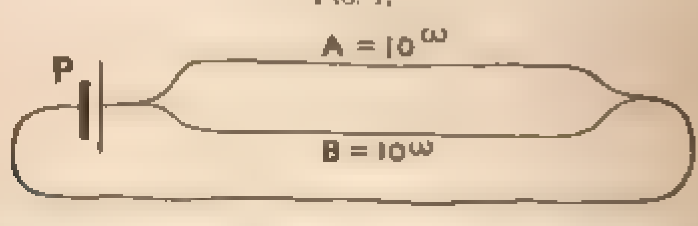
$$\frac{10}{2} = 5 \text{ ohms.}$$

Similarly, if a current of 5 amperes flows through a resistance of 10 ohms, the electro motive force capable of maintaining this current will be

$$10 \times 5 = 50 \text{ volts.}$$

When two or more channels or paths are open to a current of electricity, the current divides between them, just as water or gas in a pipe will divide into any number of branch pipes. If in the case of electrical conductors there are two wires (A and B, fig. 1), between which the current can divide, and if

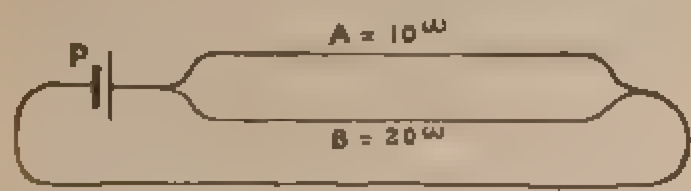
Fig. 1.



the resistances of the two wires are equal, the current will divide equally between them; thus, if a current of two amperes flows from the battery P, one ampere will go through each wire. When

the resistances are not equal, the current will divide inversely as the resistances; thus, if the resistance of one wire (A, fig. 2) is 10 ohms, and of another (B) is 20 ohms, and a current of three

FIG. 2.



amperes divides between them, two amperes will go through the wire A of 10 ohms and one ampere through the wire B of 20 ohms.

When two or more wires are joined together so that the current divides between them, they are said to be joined up in 'parallel,' and when the end of one is joined to the end of another so that the whole current goes through both wires, one after the other, the wires are said to be joined up in 'series.'

The law for double channels holds equally good for multiple channels. Thus, if there are 10 wires of uniform resistance and a current of 10 amperes divides between them, it will do so equally, so that one ampere will flow through each wire. When the resistances vary, then the current flowing through each wire will vary also, but in the inverse ratio.

When, however, two or more wires are joined up in parallel, a serious alteration is made in the condition of the circuit, for the total amount of current that is produced, whether it be from a primary battery, a dynamo-electric machine, or any other source of electrical energy, will be increased. This increase follows from the fact that when wires are joined up in parallel, their united, or, technically speaking, their joint resistance is less than that of any one of the wires taken separately. The meaning of this will be more readily apparent if a wire is regarded as a conductor rather than as a source of resistance. Thus, if two equal wires lie side by side and the current is allowed to flow through them, the conducting power of the double wire will be twice that of either wire taken separately, in precisely the same way that a water or gas-pipe two square inches in section will transmit twice as much as a similar pipe only one square inch in section. If, therefore, the

conductivity of the two wires in parallel is twice that of one of them, their united or joint resistance will be only half that of one of them. Thus, if two wires, each of 100 ohms resistance, are joined to a battery in parallel, their joint resistance will be 50 ohms. Similarly, if ten wires, each of 100 ohms resistance, are joined in parallel, they will offer a joint resistance of 10 ohms. We can, therefore, say that if any number of wires (n) of uniform resistance (R) are joined in parallel, or 'multiple arc,' as the arrangement is sometimes called, then their joint resistance $= \frac{R}{n}$. Suppose, now, that our battery has an electro motive force of 100 volts, and that its internal resistance is negligibly low, with one wire of 100 ohms joined on we get—

$$\frac{100 \text{ volts}}{100 \text{ ohms}} = 1 \text{ ampere.}$$

With two wires we get—

$$\frac{100 \text{ volts}}{\frac{100}{2} \text{ ohms}} = \frac{100}{50} = 2 \text{ amperes.}$$

This current divides equally between the two wires, one ampere going through each.

With 10 wires we get—

$$\frac{100 \text{ volts}}{\frac{100}{10} \text{ ohms}} = \frac{100}{10} = 10 \text{ amperes.}$$

Whence one ampere will still go through each wire, so that the strength of the current increases in precisely the same proportion as the number of wires. If, however, the internal resistance of the battery is proportionally high enough to necessitate its being taken into account, the reduction of the external resistance will not produce so marked an effect. With a battery resistance of 100 ohms and a single wire of a like resistance we get

$$\frac{100}{100 + 100} = \frac{100}{200} = 0{\cdot}5 \text{ ampere,}$$

and when two wires are joined in parallel we get—

$$\frac{100}{100 + 50} = \frac{100}{150} = 0{\cdot}66 \text{ ampere.}$$

With 10 wires we get—

$$\frac{100}{100 + 10} = \frac{100}{110} = 0{\cdot}90 \text{ ampere.}$$

Thus with two wires in parallel a current of 0·33 ampere would flow through each wire, while with ten wires the current strength in each wire would be only 0·09 ampere.

When the parallel circuits are of different resistance, the calculation of their joint resistance involves a little more trouble. Let us suppose two wires joined in parallel, their individual resistances being R_1 and R_2 respectively. As we have already pointed out, resistance is the converse of conductivity. Therefore, R_1 and R_2, representing the resistances, $\frac{1}{R_1}$ and $\frac{1}{R_2}$, will represent their conductivities, whence the united conductivity will be $\frac{1}{R_1} + \frac{1}{R_2}$, which is equal to $\frac{R_1 + R_2}{R_1 R_2}$. This being the joint conductivity, the joint resistance will be $\frac{R_1 R_2}{R_1 + R_2}$; thus if $R_1 = 500$ ohms and $R_2 = 1{,}000$ ohms, their joint resistance will be

$$\frac{500 \times 1000}{500 + 1000} = \frac{500{,}000}{1{,}500} = 333{\cdot}3 \text{ ohms.}$$

Briefly put, it may be said that the joint resistance of any two conductors is equal to the product of those resistances, divided by their sum.

Similarly with three (or more) wires of different resistances, their joint conductivity would be

$$\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{R_1 R_2 + R_2 R_3 + R_1 R_3}{R_1 R_2 R_3},$$

whence the joint resistance will be

$$\frac{R_1 R_2 R_3}{R_1 R_2 + R_2 R_3 + R_1 R_3}.$$

If R_1, R_2, and R_3 are 500, 1,000, and 2,000 ohms respectively, their joint resistance will therefore be

$$\frac{500 \times 1{,}000 \times 2{,}000}{(500 \times 1{,}000) + (1{,}000 \times 2{,}000) + (500 \times 2{,}000)}$$

$$= \frac{1{,}000{,}000{,}000}{3{,}500{,}000} = 285{\cdot}7 \text{ ohms.}$$

In the process of electrical testing it is frequently found to be necessary to employ wires of various resistances, either as standards for comparison, or simply for the purpose of placing in a circuit and varying the strength of the current therein. The wires are usually coiled up or wound on bobbins, so as to occupy little space, and are then placed in a convenient case or box; such a set of coils is known as a resistance-box, or rheostat. But if the coils are to be of any real value as standards, great care must be exercised, not only in accurately measuring their resistance, but also in selecting the materials of which they are made, so as to avoid deterioration or change of any kind. The wire must be completely covered throughout by some good insulating substance, to prevent contact between adjacent convolutions, and the material used for this purpose must be able to withstand without change the highest temperature to which it is likely to be subjected; and it must also be incapable of producing any injurious action on the wire. The best insulating material is silk thread, which is wound spirally over the wire in one or two layers.

In selecting the material for the wire itself, several points should be carefully attended to. The metal must be free from any liability to alteration by oxidation, &c. (iron is, therefore, unsuitable). But the most important matter for consideration is the amount of its variation in resistance, with a given change of temperature.

In very important work it is necessary to know the temperature at which a coil was originally measured, and either bring it to that same temperature during the experiment or else make a correction in the result. But either course is somewhat tedious, and in ordinary cases impracticable. In practice the coils are measured at the temperature at which it is probable they will generally be used, say 15° C. (59° F.), and the error lessened by

ng a metal whose percentage of resistance variation with
of temperature is very low.

addition to changing with any alteration in the temperature of the
atmosphere, the wire is more or less heated by the passage of
rent itself, so that its resistance may vary after ...
rapidly-performed test or experiment. An examination of
e given on page 19 shows the variation of a platinum
oy to be very small, and it is therefore very extensively
d in high-class apparatus, where the expense is a
f minor importance.

oils of high resistance it is necessary to choose a
pecific resistance is high; otherwise the length of wire
bably be inconveniently great. For low resistances
is not so important; in fact, if a metal of high
e is then used, the wire must be comparatively thick,
ength would be so short that very great difficulty would
ced in making the coils of exactly the right resistance,
a considerable difference would be caused by a slight
the length of the wire. In all cases, however, there
at advantage in the case of a thick wire, that a given
of heat raises its temperature to a less extent than would
ner wire.

pper is very unsuitable for resistance coils on account of its
variation in resistance, and, as its specific resistance is low,
uld be necessary to employ either a very long or a very fine
o make a coil of high resistance.

Taking into consideration cost, durability, high specific resistance
e and low temperature error, German silver is undoubtedly
most useful material for the purpose; and it is consequently
more frequently than anything else.

A single resistance coil — such, for example, as a standard ohm
not designed for some other special purpose — is, after having
as ordinarily wound on an ebonite or boxwood bobbin, usually
closed in a wooden case or box, furnished with an ebonite
cover. Two brass blocks or plates, to which the ends of the coil
wire are soldered, are screwed on to the under side of this cover.
Connection with the external circuit is made by means of terminals
fixed on the top of the case, and connected electrically with the

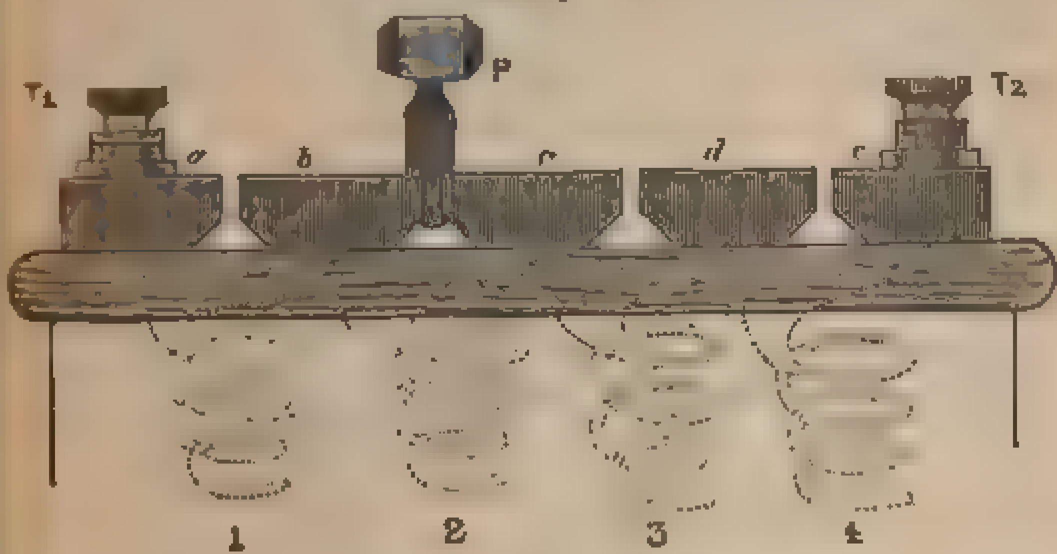
of terminal or binding screw shown in fig. 3
objection, the contact being as a rule uncertai
in which dependence for good contact has real
the end of a screw (frequently pointed as if to a

Fig. 3.

should be eschewed, at least for small wires
readily bent with the fingers. A much bett
terminal is that shown in fig. 4, where the wir
a fixed base and a screw nut. In tightenin
effect is produced, which assists in removin
either on the wire or on the terminal, and so

into any particular circuit can be varied at will from the zero to the maximum, special devices have to be employed to obtain this result with the smallest possible waste of time. Fig. 5 shows the

FIG. 5.



best method of casing a number of coils of various resistances; all the coils are joined in series, and the junction of each pair is soldered to the bottom of a brass block, as shown in the figure, great care being taken in winding to ensure the absence of contact or leakage between one portion of the wire and another. The bobbins are fixed to the under side of the ebonite top of the case, the wires being connected to the brass blocks *a*, *b*, *c*, *d*, *e*, which are firmly fixed to the upper side of the ebonite, the adjacent ends of the various blocks being turned out to receive a slightly tapered or conical brass plug. The end blocks are fitted with terminal screws, T_1 and T_2, to which any extraneous wires can be connected. Now, if a wire leading from the copper pole of a battery is joined to a terminal, T_1, and another from the zinc pole to T_2, a current will flow through the resistance box, starting from the left hand block *a* and passing through the resistance coil No. 1 to the second brass block *b*. Here it has two paths open to it; one through the coil No. 2, of comparatively high resistance, the other through the brass plug P, which has, practically, no resistance at all. All the current will therefore pass by the latter path, and none through the coil, which is said under these circumstances to be 'short-circuited' by the plug P. The

current must pass through the coils 3 and 4 before it reaches the terminal T_2.

The brass plug, which should be furnished with an ebonite cap or top, must be carefully tapered to fit the hole *exactly*. Should there be the slightest shake, or should there be any dirt or grit on the blocks or on the plug itself, the contact will be uncertain and the resistance variable. When properly made, the plug on being inserted with some pressure and a slight twist—say to the right should fit so thoroughly that on raising it the resistance box should be lifted with it. To remove the plug it should be necessary to first loosen it by giving a slight twist to the left. The lower and the two vertical edges or corners of the blocks should also be filed away to give a larger ebonite insulating surface between the blocks and to allow this surface to be kept clean. This arrangement is necessary in order to prevent, as far as possible, any short-circuit being caused by the accumulation of dust and dirt.

Resistance coils fitted in this way can easily be put in or taken out of the circuit, by withdrawing or inserting plugs between the brass blocks to which the ends of the various coils are soldered. It is hardly necessary to remark that the surfaces of contact should not be lacquered, but should be kept bright and clean.

Resistance coils are frequently used in conjunction with and in the immediate vicinity of delicate measuring apparatus in which a sensitive magnetised needle is employed. If, in such cases, the coils are wound continuously on the bobbin, or in the same manner as a solenoid, an electro-magnetic field of force will be set up immediately a current is sent through the coils, which may be sufficiently strong to impart motion to the needle. If the instrument is being employed to measure the current passing through the resistance, or any effect of that current, serious errors may therefore be introduced by the direct effect of the coils upon the needle. Again, as we shall see later on, it is impossible to start or stop a current in a solenoid suddenly, because work is done and time occupied in establishing, and again in disestablishing, the electro-magnetic field. These are serious defects, and it is fortunate, therefore, that the remedy is simple.

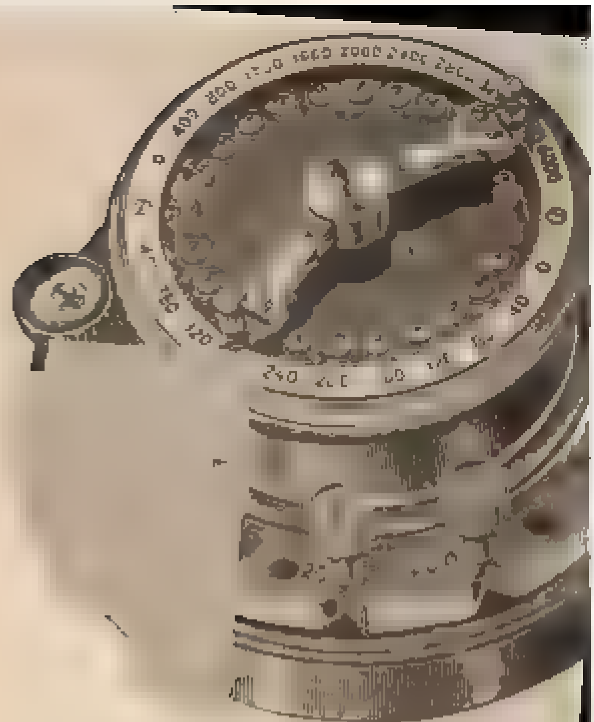
To obviate the difficulty it is only necessary that the w

uld be wound 'double' that is to say, the required length ould be measured off and then doubled in the middle, the two lves being wound on together. The meaning of this will rhaps be more apparent on referring to the illustration (fig. 5). e double winding is more easily managed, especially with long ils, by winding the two halves off two separate spools or bobbins d soldering the inner ends together. In either case the two tremities of each coil are brought out together. We have thus o similar helices or solenoids carrying currents equal in strength t opposite in direction. The consequence is that the disturbing ect which would be produced by one solenoid is counteracted neutralised by the opposite effect which would be due to the her.

When the coils to be enclosed in a box are numerous, it is onvenient to place them in one long row and thus make a long rrow box. It is preferable to arrange them in two, three, or re parallel rows, connecting these rows together by brass blocks d plugs, as indicated in fig. 6. The centre of each block should

Fig. 6

o be provided with a tapered hole of the same size as those tween the blocks, in order that the plugs may be placed in m when not in use for short-circuiting the coils. It is most portant that all the holes and all the plugs should be of exactly e same dimensions, so that the plugs may be interchangeable, that any one plug may be used for any of the holes. Failing s, considerable inconvenience and risk of error would speedily ne, for then there would be a particular plug for each hole,



or box provided with an ebonite top and mou
base Ten coils, each of 40 ohms resistan
eleven rounded steel points projecting throug
the instrument. Ten other coils, each of
are connected to the steel points on the othe
of the ebonite. A number of other coils
brass blocks fixed on the base of the instru
those already described ; when not required

ass through the 40 ohm coils until it reaches the steel spring ed by the front brass arm, which is movable over these coils tuds. Passing along this arm, which is metallic throughout, ll enter the other movable arm and thence pass to the hm coils. Leaving at the zero stud of these 400-ohm coils e left-hand side, it will pass by a thick wire direct to the left- terminal and so to the other part of the circuit. The two can be readily moved round over the steel studs or points, at the range of one arm is from 0 to 400 ohms, and that of ther from 0 to 4,000 ohms. The total resistance in circuit the arms as shown, and all three plugs *in*, is 3,880 ohms. ugh it is a great advantage that the resistance can be very y varied, the instrument is somewhat objectionable for te measuring purposes, as the springs are apt to get weak he contact unreliable, the resistance then becoming variable. nother method of casing and joining up resistance coils is n in figs. 8 and 9. A (fig. 8) is a circular brass plate; *b*, *c*, *d*

FIG. 8.

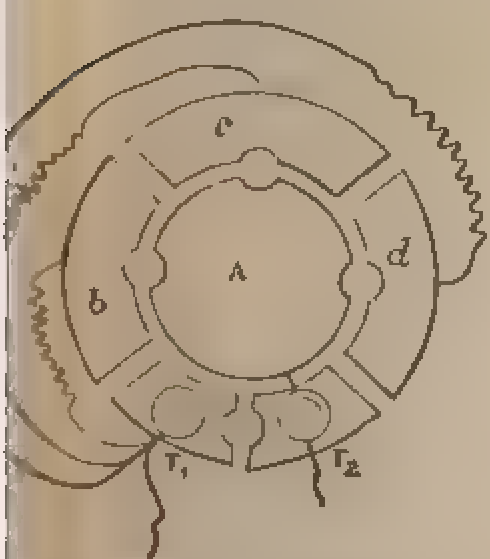
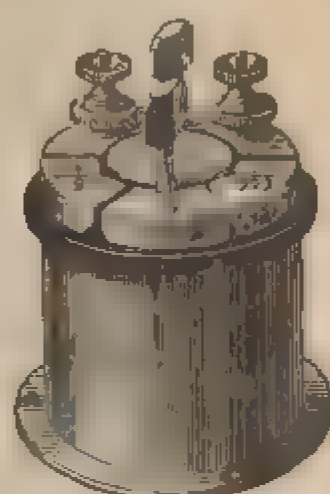


FIG. 9.



ass blocks. A tapered hole is provided between each of outer plates and the plate A for the usual conical plug. are the terminal screws, the latter of which is permanently cted to the brass plate A. One end of each of the three s soldered to terminal T_1, and the other end of each to one er of the outer brass blocks. When it is desired to *insert* circuit one of the resistance coils, the plug is placed in the

hole which is between the block connected to that coil and the plate A.

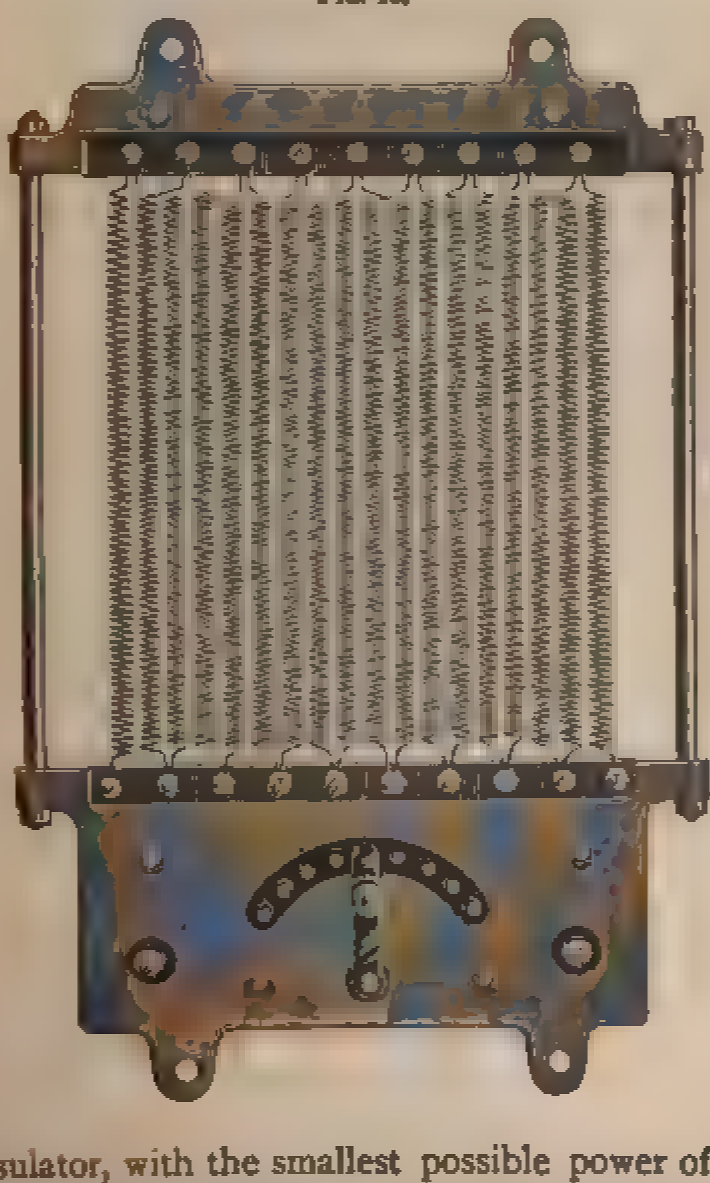
Thus the action is the reverse of that described in the last method, for here we insert a plug to insert resistance, removing it to cut out the resistance. Only one coil can, however, be used at a time; and if the plug is placed between terminals T_1 and T_2 the whole box is short-circuited. Fig. 9 shows a box of coils connected according to this method. It is designed for use with a galvanometer as a set of 'shunt coils,' having respectively $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$ of the resistance of the galvanometer. (The nature and applicability of shunt coils will be dealt with in Chapter IV.)

For general use as well as for accurate measurements, the form of resistance-box shown in figs. 5 and 6 should be used. But where a means of rapidly varying the resistance is necessary, the form shown in fig. 7 is often employed. As we have already remarked, resistance varies considerably with temperature, whence every set of coils should have marked on the case the temperature at which they were measured. Then for very accurate tests they may either be brought to that temperature or a correction made in the reading, but in any case it is known whether any great error is likely to be caused by using them at any particular temperature.

It sometimes happens, however, that sets of resistance coils are required merely for the purpose of dissipating a certain amount of electrical energy. For instance, it becomes necessary, when employing some dynamo electric machines, to reduce the electrical output in response to a correspondingly reduced demand made upon it by the external circuit; and this can be done by joining extra resistance in series with the magnet coils, and allowing some of the power to be expended in heating this extra resistance. In such cases it is not necessary to know exactly the value of the resistance in ohms, but it must be divided into a number of approximately uniform sections, so that its value can be changed gradually. As the currents employed are, in such cases, very powerful, it is important that the coils should be able to withstand a considerable rise in temperature without being in any way injured. The wire must therefore be left bare, so that the heat generated can be dissipated by radiation and convection. Were the wire to be covered with any insulating material, the dissipation

by both these processes would be impeded, and there would be the further disadvantage that this sheathing would be sooner or later damaged, if not destroyed. The wire should be of a metal which has a fairly high specific resistance and fusing point, and should not be liable to deterioration by combining with atmospheric oxygen. For these reasons, German silver and tinned or galvanised iron are usually employed, but in special cases platinoid is resorted to. It is essential to select for the supporting frame a material which, while strong, is also non-inflammable and

Fig. 10.



a good insulator, with the smallest possible power of condensing atmospheric moisture upon its surface. In fig. 10 is shown such a set of resistances, constructed by Messrs. Goolden & Co., and

suitable for carrying very heavy currents. There are two cast iron end frames, which are hollow and have slate slabs fitted into them, these slabs being held in position by bolts which pass through both the slate and iron frame. The slabs, projecting inwards from the frames, carry a series of brass bolts and nuts, on to which are fixed the ends of spirals of bare German silver wire. Slate is an effective insulator for the purpose, and the device of passing the connecting bolts right through it and securing them with nuts, instead of trusting to a screw-thread cut in the material, renders it mechanically satisfactory. The frame is completed and made rigid by a pair of iron rods which are secured to the cast iron ends. The whole of the spirals are joined in series, the terminals for connection to the external circuit being fixed on to the slate through holes in the bottom end-frame. The left hand terminal is joined to the bottom of the left-hand spiral, while the right hand terminal is connected to the lever of a switch which passes over nine contact pillars rising from the slate bed through an opening in the frame. These pillars are connected to the lower junctions of the spirals, and by altering the position of the switch the spirals can be cut in or out of circuit, in pairs, as desired. The iron frames are 12 inches in width, the length being varied up to about 2 feet 6 inches by the employment of connecting rods of different lengths. A set of resistances similar to that illustrated is capable of dissipating about 1,000 watts without undue heating.

We have seen that whenever a current of electricity flows, a certain amount of energy is expended; and it is necessary to be able to measure exactly, the amount of energy so expended in any circuit or in any part thereof. The quantity of work performed in raising a mass of one pound through a difference of level of one foot against the force of gravity, is generally taken as the unit of mechanical energy and is known as the foot-pound. The work done in raising any mass through any height, is found by simply multiplying together the number of pounds in that mass by the number of feet through which it is lifted. Somewhat similarly we can take as the practical unit of electrical energy, the amount expended in transferring a unit quantity of electricity (one coulomb) through a difference of potential of one volt. And by multiplying the number of coulombs which have flowed from one

point to another by the difference of [illegible]
those points, we obtain the number [illegible]
expended during the passage [illegible]
trical energy, or one coulomb [illegible]
joule. As a simple numerical [illegible]
of 10 amperes to flow for 5 seconds [illegible]
passing through the circuit would be [illegible]
current were maintained by a potential difference [illegible]
amount of energy expended in that time would be [illegible] = [illegible]
joules.

As a rule we wish to know the *rate* at which work [illegible]
done in any circuit, rather than the amount which is done [illegible]
given time. It is evident that this rate [illegible]
dividing the amount of work by the number [illegible]
its performance, but the same result can be arrived at [illegible]
ing together the potential difference and the rate of [illegible]
flow of electricity, instead of the quantity [illegible]
given time. Now the rate of flow of [illegible]
as the current strength, which is [illegible]
fore, if the difference of potential [illegible]
is multiplied by the resulting current [illegible]
the rate at which energy is being [illegible]
between those two points. The [illegible]
of *power* is called the *watt* [illegible]
1 watt. Therefore, if a difference of potential [illegible]
the ends of a wire maintains a current of [illegible]
of working is 3 × 20 = 60 watts.

It is desirable that the [illegible]
trical rates of working [illegible]
unit is termed the [illegible]
working which, if continued [illegible]
foot-pounds of energy [illegible]
One horse-power is equal to 746 [illegible]
lated the number of watts [illegible]
dividing this number by 746 [illegible]
loss of energy expressed in [illegible]
is, therefore, frequently [illegible]

Subsequent to the passing by [illegible]

[illegible]

the Board of Trade the arbiters of the destinies of electric lighting concerns, a larger unit of electrical power has come into use. It is sometimes called the Board of Trade unit of power (but see p. 615), and is equal to 1,000 watts, or the power expended by 1,000 amperes at a potential difference of 1 volt. A convenient name for this unit is the kilowatt.

The units described in this chapter are those which are, and which will continue to be, employed in practice by the electric lighting engineer. No effort should therefore be spared to master the simple relation existing between the ampere, volt, ohm, horse-power, &c.

But it is advisable to know the method by which the various electrical units have been evolved, for they have not been selected arbitrarily, like the pound, yard, and gallon, but are built up on the fundamental conceptions of length, time, and quantity of matter, and are inseparably linked together. Perhaps the simplest measurable quantity which we can conceive is that of length, and in deciding upon a unit of length an effort was made to select some unalterable natural distance. The length of an earth quadrant that is, the distance from the equator to the pole along a meridian—was agreed upon, and one ten-millionth part of this taken as the practical standard of length, and called a metre. The original measurement of the earth quadrant proved to be considerably in error, and consequently the simple relation between it and the metre was upset. But the metre thus determined is retained as the standard of length, and one hundredth part of that length, called one centimetre, is taken as the basis of the units upon which the system now to be briefly described has been reared. A square centimetre is the area contained in a square each of whose sides is one centimetre, and a cubic centimetre is the volume contained in a cube each of whose edges is one centimetre in length.

The next unit required is that of mass, or quantity of matter, and it should be remembered that the force of gravity acts upon every body in exact proportion to its mass, or the quantity of matter in it, independently of its size; therefore, what we know as the weight of any substance is exactly proportional to its mass. The unit of mass is called the gramme. It is equal to the mass

contained in a cubic centimetre of pure water at its maximum density, i.e. at 4° Centigrade.

The third unit, that of time, is called the second. It is the length of time known in England by that name, and is the 86,400th part of a mean solar day.

The great value of a system built upon such units as those described is that it is always possible to recover any one of them, and so reconstruct or verify the system if necessary, although the process is no doubt difficult and tedious. The term 'absolute' has been applied to such a system, but it is not easy to see the precise application of the word here. It is usual, and certainly far better, to refer to it as the centimetre-gramme-second, or the C.G.S., system.

The next conception in order of simplicity, is that of the rate at which a mass of matter changes its relative position, or the velocity with which it moves. Velocity is estimated by dividing the distance in centimetres through which a body moves by the time in seconds taken to travel that distance. The unit is a velocity of one centimetre per second.

A mass of matter cannot, by any property belonging to it, change its position or its state of rest or motion, by itself. That which is competent to move, stop, or vary the motion of a mass of matter is called force, and the greater the force, and the longer the time during which it acts, the greater will be the increase or decrease in the velocity of a given mass. The unit of force is called the dyne; one dyne is that force which, by acting upon a mass of one gramme during one second, can impart to it a velocity of one centimetre per second.

When the position of a body is changed in opposition to any resisting force, work is done or energy expended, the amount being estimated by multiplying together the force overcome and the distance through which it is overcome. The unit of work is called the 'erg,' and is that work done when a force of one dyne is overcome through a distance of one centimetre; the energy expended is in every case equal to the work done, therefore the erg is also the unit of energy. We have seen that the practical unit of work, or expenditure of energy, is the joule; and one joule is equal to ten million ergs. Consequently, the practical unit of power, or

rate of doing work, called the watt, is equivalent to ten million ergs per second.

Current strength is measured by the quantity of electricity which flows past any point in a circuit per second. The unit is that current strength which, when one centimetre of its path—that is to say, one centimetre of the conductor carrying the current—is curved into an arc of one centimetre radius, exerts a force of one dyne upon a unit magnet pole placed at its centre. The conditions of this unit will, however, be better understood after studying Chapter IV. The practical unit which is called the 'ampere' is equal to one-tenth of this so-called 'absolute' unit.

The unit quantity of electricity is that quantity conveyed by unit current in unit time. The practical unit, the coulomb, is therefore also one tenth of the absolute unit.

The unit difference of potential between two points exists when one erg of work has to be performed in urging one unit of electricity against the electric force, or when one erg is expended by the flow of one unit of electricity from one point to the other. The volt or practical unit is 100,000,000 times the absolute unit.

Unit resistance exists when unit difference of potential causes unit current strength to flow through it. It follows, therefore, that the ohm is equal to 1,000,000,000 absolute units. The units which chiefly claim our attention are those of current, quantity, potential difference, and resistance. It is not possible to provide an invariable physical standard of either of these except resistance, which fact to a certain extent increases the importance attached to the unit of resistance. As has been pointed out, a reliable physical standard, in the form of a column of mercury of certain dimensions, has been selected to represent the ohm.

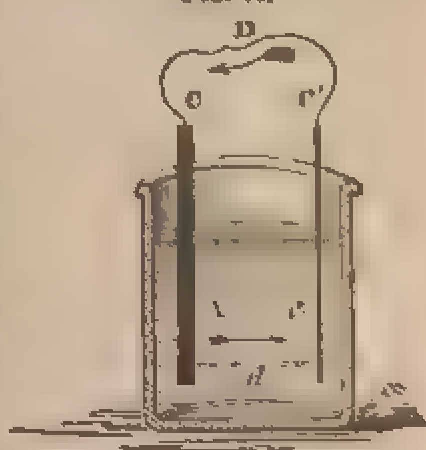
CHAPTER III.

PRIMARY BATTERIES.

CURRENT of electricity can be maintained in a number of ways. ne of these is by means of primary cells. A primary cell consts of a vessel containing a saline or acidulated solution, in which e immersed two solid conducting bodies, one of which is more sailable than the other by the liquid. When two or more cells re joined together to increase the effect, the combination is known a battery.

Primary cells can be divided into two classes, viz. (*a*) singleuid, or those in which only one solution is used, and (*b*) doubleuid, or those in which two solutions e employed.

Fig. 11.



The single-fluid cells are typified y the 'simple cell,' which was referred o on page 2, and which consists of glass or earthenware vessel (fig. 11) early filled with water acidulated with small proportion of, say, sulphuric cid, and containing a piece of zinc, A, nd a piece of copper, B. On connectg the plates by a piece of wire, C C, nd thereby causing the current to flow, the surface of the zinc attacked and sulphate of zinc is formed, hydrogen gas being berated at the surface of the plate B.

This reaction may be represented by an equation, thus :—

$$\underset{\text{Zinc.}}{Zn} + \underset{\text{Sulphuric acid.}}{SO_4H_2} = \underset{\text{Sulphate of zinc.}}{SO_4Zn} + \underset{\text{Hydrogen.}}{H_2}$$

No chemical effect whatever is produced on the surface of the ate B, and it may here be noticed that the plate which is more

or less dissolved, is called the positive plate, the other being called the negative plate. Chemical action may be supposed to take place throughout the entire length of the liquid or the distance between the plates, but it is not manifest except at the surfaces of the plates, and, for convenience' sake, it may be said to commence at the positive plate that is to say, the acid particles, or, more correctly speaking, molecules in contact with the zinc plate may be assumed to be the first decomposed, the hydrogen thus liberated attacking the next succeeding acid molecules in a similar manner. Hydrogen is again liberated, which again in its turn decomposes the adjacent acid molecules. A series of decompositions and recompositions is thus propagated throughout the entire liquid by a process of repetition, molecule for molecule, resulting finally in the deposition of the free hydrogen on the copper or negative plate. As the hydrogen thus deposited does not enter directly into chemical union with any of the simple metals, it remains in the gaseous state. The resultant changes present the appearance of the acid alone being affected, while the water remains constant and unchanged. The action may be expressed in chemical formulæ, thus :—

Before action.

$$\left|\ \overline{SO_4H_2}\ \overline{SO_4H_2}\ \overline{SO_4H_2}\ \overline{SO_4H_2}\ \overline{SO_4H_2}\ \right|$$

Zinc or + Copper or −

In action.

$$\left|\ \overline{SO_4}\ \overline{H_2SO_4}\ \overline{H_2SO_4}\ \overline{H_2SO_4}\ \overline{H_2SO_4}\ \overline{H_2}\ \right|$$

Zinc or + Copper or −

The hydrogen is here released in a definite ratio to the amount of zinc dissolved. In fact, we may take it as an established law that the ratio between the weight of zinc dissolved and that of the hydrogen, &c., released by the passage of the current, is invariable, and that this ratio is dependent upon their respective electro-chemical equivalents.

We see by the above equation that for every atom or equivalent of zinc dissolved or converted into sulphate of zinc, two atoms of hydrogen are liberated. An atom may be defined as the smallest possible quantity of any substance capable of entering or passing out of combination ; and it will be seen, on

[redacted]

referring to the accompanying table of atomic weights, or of the relative weights of individual atoms of some of the more important substances, that an atom of hydrogen weighs less than one of any other substance :—

TABLE OF ATOMIC WEIGHTS AND EQUIVALENTS.

Elements	Symbol and Valency	Atomic Weight	Chemical Equivalent	Electro-chemical Equivalent (Milligrammes per Coulomb)
ELECTRO POSITIVE.				
Hydrogen . . .	H^1	1·	1·	·010384
Potassium . . .	K^1	39·04	39·04	·40539
Sodium . . .	Na^1	22·99	22·99	·23873
Aluminium . . .	Al^3	27·3	9·1	·09449
Magnesium . .	Mg^2	23·94	11·97	·12430
Gold	Au^3	196·2	65·4	·67911
Silver	Ag^1	107·66	107·66	1·11800
Copper (Cupric) . .	Cu^2	63·	31·5	·32709
,, (Cuprous) .	Cu^1	63·	63·	·65419
Mercury (Mercuric) .	Hg^2	199·8	99·9	1·03740
,, (Mercurous) .	Hg^1	199·8	199·8	2·07470
Tin (Stannic) . .	Sn^4	117·8	29·45	·30581
,, (Stannous) . .	Sn^2	117·8	58·9	·61162
Iron (Ferric) . .	Fe^3	55·9	18·64	·19356
,, (Ferrous) . .	Fe^2	55·9	27·95	·29035
Nickel . . .	Ni^2	58·6	29·3	·30425
Zinc	Zn^2	65·	32·5	·33696
Lead	Pb^2	206·4	103·2	1·07160
ELECTRO-NEGATIVE.				
Oxygen . . .	O^2	15·96	7·98	·08286
Chlorine . . .	Cl^1	35·37	35·37	·36728
Iodine . . .	I^1	126·53	126·53	1·31390
Bromine . . .	Br^1	79·75	79·75	·82812
Nitrogen . . .	N^3	14·01	4·67	·04849

It is in consequence of this fact that hydrogen is taken as the standard in calculating the atomic weights of the various simple or elementary bodies. It will also be observed that an atom of zinc weighs sixty-five times as much as an atom of hydrogen. The meaning of the equation, therefore, is that for every sixty-five parts by weight of zinc dissolved, two parts by weight of hydrogen are liberated ; consequently, if we again regard the relative deposition of hydrogen as the standard, the weight of zinc dissolved will be 32·5 times as much, or, in other words, the electro-chemical equivalent of hydrogen being unity, that of zinc is 32·5. The equi-

valents of the other elementary bodies enumerated in the table have been calculated in a similar way.

The liberated hydrogen, in consequence of its low specific gravity, exhibits a tendency to rise through the water and escape into the air. Only a portion, however, of the gas escapes in this way, a large proportion adhering to the copper plate and forming, as it were, a gaseous film over the metallic surface. This accumulation, due to a variety of causes, is facilitated by the opposite polarities or electrical conditions of the copper and hydrogen which cause a mutual attraction to set in. There is a double effect of the accumulation which soon becomes apparent, for a gradual diminution in the current sets in, consequent first on the decrease in the copper surface exposed to the liquid (which involves a proportional increase in the internal resistance of the cell), and, secondly, on the tendency on the part of the positively electrified hydrogen film to set up a contrary current. Free hydrogen is, in fact, more positive than the zinc itself. When this condition is arrived at, the cell is said to be polarised. The effect of the passage of a current being, therefore, a reduction of the electro-motive force of the cell, such a combination is manifestly useless for purposes requiring a continuous and uniform current.

FIG. 12.

To overcome this really strong objection Smee constructed a cell (fig. 12), the peculiarity of which consisted in the nature of the surface of the negative plate. It had been ascertained that a smooth surface engenders a much more rapid accumulation of hydrogen than does a roughened surface. Accordingly, he used for his negative plate a thin sheet of silver covered with platinum in a state of very fine division, so that an irregular surface was produced. So treated the plate is known as platinised silver. There are two zinc plates connected to the same terminal, but placed one on each side of the silver, the solution being 1 of acid to 10 of water. This cell, which is still largely used, is considerably more lasting than the simple cell; the unevenness of the negative surface facilitates the ascension of the hydrogen

[redacted]

particles more nearly in proportion to the rate of production. It has also a higher electro-motive force because of the substitution for copper of a more electro-negative plate. This form of battery is useful where currents are required for brief periods, but it is far from being a constant cell, that is, one which yields a *continuous and uniform* current. When, however, the cell is put together of abnormally large proportions, it approximates more nearly to the condition of a constant cell, and is used as such by many electro-platers.

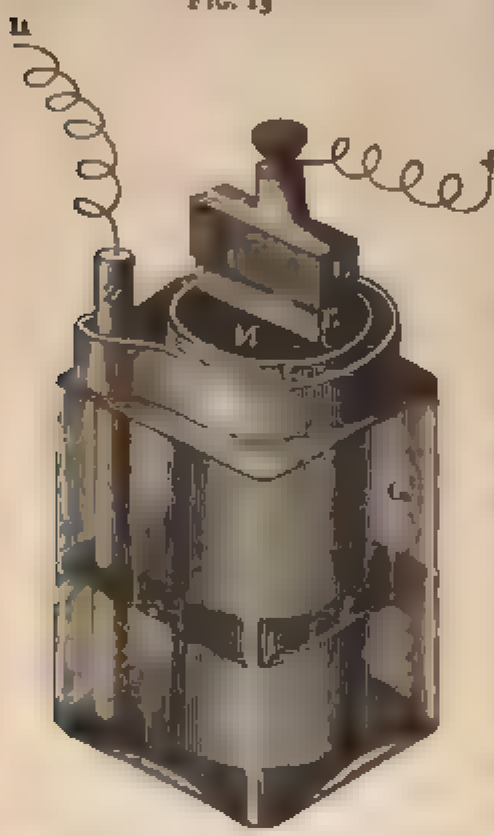
The Smee cell is capable of being manufactured in a very compact form. The silver foil is fixed in a frame made by fastening together four pieces of wood about half an inch square in section, the upper edge of the foil being connected to a brass terminal on the top of the frame. The plates of zinc, a trifle larger than the foil, are placed against the two sides of the frame and all three are then clamped together by a strong brass terminal or clamp which is placed in contact with the zincs. The advantage gained by this form of construction is that the internal resistance of the cell is very low; first, because the two zinc plates are opposite to the two sides of the foil, and, secondly, because the distance between the foil and the zincs is very small. The wooden frame is necessary, to support the thin silver foil and to prevent it touching either of the zinc plates. Were there any other simple means of preventing this contact, the frame might be dispensed with.

There is in use at the Royal Observatory at Greenwich a remarkably simple and useful modification of the Smee cell. It consists of a plate of zinc and a plate of platinized carbon, the upper portion of which is rendered non-porous by immersion in hot paraffin wax. The solution is one of dilute sulphuric acid, the acid being, however, very pure. The hydrogen bubbles can be seen rising freely through the solution, instead of adhering to the uneven surface of the negative plate. The resistance of the cell is very low, and its electro-motive force, after a few minutes, remains steady at about half a volt.

A far more important cell than the Smee is the Leclanché (fig. 13), in which a zinc rod, z, is used as the positive plate, while the negative plate c takes the form of a rod or slab of gas carbon, or

of prepared carbon. The gas carbon is one of the by-products in the manufacture of gas, and is formed by the condensation of a portion of the carbon in the cooler portions of the retort. The prepared carbon is made by subjecting to considerable pressure, at a high temperature, a mixture of powdered carbon and some treacly substance which is employed for cementing the carbon particles. The carbon plate is placed inside a vessel of porous (unglazed) earthenware, which is then filled with a mixture of crushed, but not powdered, carbon and black oxide of manganese. The latter should be of the 'needle' or granular form, care being taken to exclude powder or dust. The outer vessel, G, is generally of glass, which enables the condition of the cell to be observed without removing any of the parts. The liquid consists of a saturated solution of sal ammoniac, or chloride of ammonium, the porosity of the inner jar allowing the solution to diffuse itself somewhat freely, and so to moisten the mixture of carbon and black oxide.

FIG. 13



The zinc combines with the chlorine of the sal ammoniac, forming zinc chloride, simultaneously releasing hydrogen and ammonia, which latter dissolves in the water until a saturated solution is obtained—that is to say, until the solution holds as much as it can support—after which it escapes as a gas readily recognised by its characteristic odour. It may, however, be remarked that water is not saturated with ammonia until it has absorbed 727 times its volume of the gas at a temperature of 15·5° C. or 60° F. The hydrogen, so far, remains free, as shown by the equation:—

$$\underset{\text{Zinc.}}{Zn} + \underset{\text{Sal ammoniac.}}{2NH_4Cl} = \underset{\text{Zinc chloride.}}{ZnCl_2} + \underset{\text{Ammonia.}}{2NH_3} + \underset{\text{Hydrogen.}}{H_2}$$

It is, however, ultimately released inside the inner vessel, and there it deprives the manganic oxide of some of its oxygen, forming water and sesqui-oxide of manganese, thus :—

$$\underset{\text{Hydrogen.}}{H_2} + \underset{\text{Manganic oxide.}}{2MnO_2} = \underset{\text{Water.}}{OH_2} + \underset{\text{Sesqui-oxide of manganese.}}{Mn_2O_3}$$

The entire action may be represented by a single equation, thus :—

$$Zn + 2NH_4Cl + 2MnO_2 = ZnCl_2 + 2NH_3 + OH_2 + Mn_2O_3.$$

The action so represented is, of course, similar to that of the simple cell or the Smee, in so far as concerns the propagation of the series of decompositions and recompositions. There is, however, a subsequent or secondary reaction between the zinc chloride and the other constituents of the solution, resulting in the formation of what are called double salts, which tend to impede the efficient working of the cell.

One great advantage this battery has over most, if not all other forms, is that it does not in any way deteriorate by inactivity, unless the evaporation of the water can be regarded in this light, but even that may be prevented. It is no unusual experience for these cells to remain in work for upwards of a year without the necessity for any attention whatever, and even then it is probable that a jug of water is all that is required. It will be seen, from a study of the equations given above, that the working of the battery results in the gradual absorption of the zinc, and the decomposition of the sal ammoniac, &c., which accordingly require replenishing at times. A whitish yellow turbidity in the solution indicates the presence of an excessive amount of zinc chloride in proportion to the amount of sal-ammoniac, which latter should then be increased, although it would be as well to remove a portion of the solution and then fill up with water before adding the sal ammoniac.

Considerable care is taken in the construction of this cell. As both sal ammoniac and ammonia are corrosive and attack copper, brass, &c., all the exposed metallic surfaces should be well served with gutta percha, pitch, paraffin wax, or some other non-corrosive and impervious material.

Where the batteries are made in very large quantities, it is the practice to drill two small holes through the upper extremities of the carbons, and, after raising these ends to a high temperature, to dip them into melted paraffin wax. They are subsequently placed into a mould containing molten lead, a terminal or binding-screw being cast into this leaden cap at the same time. The function of the wax is to close the pores in the upper portion of the carbon, and so to prevent the ammoniacal solution from creeping up to the terminal or leaden cap. Lead is interposed between the waxed carbon and the brass terminal because it is the least assailable of the ordinary metals. Pitch is run over the carbon-manganese mixture to keep the mixture and the carbon rod in position, and to form an impervious covering, holes being made in it, however, to permit any hydrogen or other gases that may be formed to escape. The upper parts of the porous pot, and the zinc rod and the connections, are likewise coated with pitch. Sometimes an india rubber cover is made to fit over the top of the battery, so as to hold the porous pot and the zinc permanently in position, and to prevent the evaporation of the water.

The electro-motive force of this battery is nearly twice that of the Smee, while, owing to the large surface exposed, more particularly at the negative plate, the internal resistance is also low. The cell is, however, only useful for sending occasional or intermittent currents, such as are required in electric-bell work. In fact, the chief objection to this battery is the great rapidity with which it polarises and so becomes temporarily useless, owing probably to the fact that hydrogen is liberated faster than the manganic oxide can be decomposed. Consequently, a more or less perfect film of hydrogen is deposited over the surface of the carbon. That this is the case is in a measure demonstrated by the fact that if the cell is allowed to stand idle for a brief interval of time it will again yield its full current. This intermittent action obviously limits very materially the cell's sphere of usefulness. The defect, although very marked when the resistance of the circuit is very low, is reduced to a minimum when the resistance is high, because the current is then feeble and the chemical reactions proportionately less. The fact that the constituents of the cell remain inactive when the cell is idle, is a point

of very considerable importance, and is a very useful feature, for it means that there is no wasteful action in the battery, such as we shall find there is in practically every other type of battery at least, in every battery in which an acid plays a part. Cleanliness is, however, absolutely necessary in dealing with the Leclanché, or, indeed, with any other form of battery, and it is essential that the containing vessel, whether of glass or earthenware, should be kept dry externally. The latter desideratum is usually accomplished by coating the upper portion of the outer surface of the vessel with pitch or some other such substance as will not permit the liquid to 'creep' over its surface, for the salt (sal ammoniac) has a strong tendency to crystallise out. Should the solution be allowed to creep, we have to contend not only with the waste of salt so occasioned, but also with the 'leakage' of electricity that would take place over the moistened external surface.

There is a modification of the Leclanché which is of some importance and which is known as the 'agglomerate' Leclanché. The negative element consists of a carbon plate or block, having in contact with it blocks of agglomerated carbon and manganese. The latter are prepared by intimately mixing 40 parts of manganic oxide, 55 parts of gas carbon, and 5 parts of gum lac resin, and submitting the mixture, placed in a steel mould, to a temperature of 100° C., applying at the same time considerable hydraulic pressure. The result is a solid compact mass, and, as the chief function of the porous pot in the older type is to support the mixture of crushed carbon and manganic oxide, it is apparent that that vessel, which materially increases the internal resistance of the cell, can be dispensed with. India-rubber bands placed round the agglomerated blocks (which in their turn embrace the carbon block), keep the whole of the compound negative element together. In the earlier forms of agglomerate cell, rectangular blocks of agglomerated manganic oxide and carbon were held against the two faces of a flat plate or block of carbon, and the india rubber bands holding the three blocks together were specially made so as to hold also the zinc rod, which was of the usual type.

But a much better form is that known as the 6-block agglomerate (see fig. 14), which is very extensively used. The negative element consists of a block of carbon with six fluted sides,

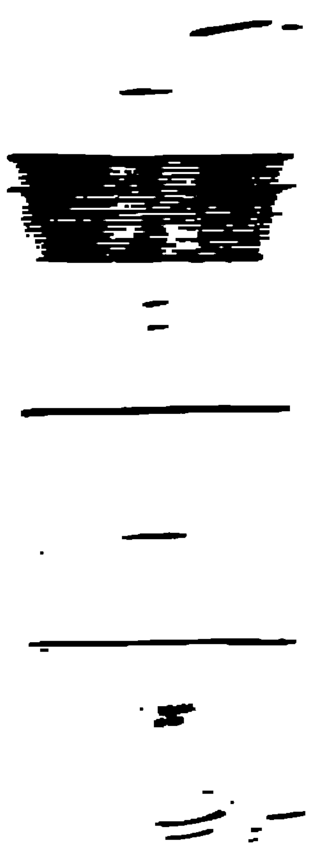
which is capped with lead and fitted with a terminal after the top of it has been steeped in hot paraffin wax. In each of the sides is laid a round stick of the agglomerated carbon and manganese oxide, the whole being wrapped round with a piece of coarse canvas, and held in position by a couple of stout india rubber bands. The canvas does not, of course, prevent intimate contact between the rods and the solution, nor does it appreciably increase the internal resistance of the cell, its function being simply to prevent pieces of the agglomerate rods falling out and 'short circuiting' the cell, by joining the positive and negative elements together. Instead of employing a zinc rod for the positive element, a large piece of sheet zinc (about $\frac{1}{8}$ inch thick) is rolled into a cylinder, the approaching edges being, however, kept a quarter of an inch or so apart to allow of the free circulation of the solution. In consequence of the very large increase of the amount of surface thus exposed to the liquid, the internal resistance is very considerably reduced, polarisation being also to a great extent prevented or at least impeded. The current produced is much more uniform than that from the old type Leclanché. As a matter of fact, when employed upon circuits offering high resistance, an almost constant current is produced, and, as the cell is pre eminently a clean one, as the cost of maintenance is very low, and as there is a total absence of wasteful action when the cell is idle, it is rapidly gaining ground and driving out of the market many other types of cell, such as the Daniell and the Bichromate (to be presently described). In fact, for ordinary work on circuits of high resistance, or even for hard but intermittent work on circuits of low resistance, we know of few, if any

FIG. 14.

[redacted]

serious [illegible]
the important [illegible]

[illegible]
is an important [illegible]
motive force [illegible]
purposes of measurement [illegible]
a small glass [illegible]
test-tube [illegible]
M, being [illegible]
which covers the [illegible]
to a depth of [illegible]
is placed the [illegible]
consists of a [illegible]
mercurous sulphate [illegible]
of zinc sulphate. [illegible]
rod of pure [illegible]
the paste. [illegible]
means of paraffin [illegible]
Connection is made [illegible]
of a copper wire [illegible]
end of the [illegible]
A platinum wire [illegible]
contact with the mercury.



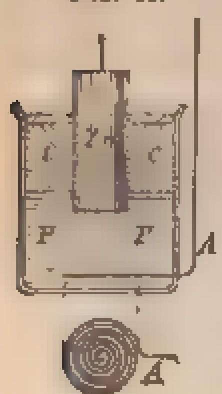
It is highly [illegible]
absolutely pure [illegible]
mercury. [illegible]
pure mercury [illegible]
sulphate is [illegible]
with distilled water [illegible]
remove any trace of the mercuric [illegible]
mercuric contains [illegible]
curous sulphate [illegible]
yellowish tinge.

The chemical action which takes [illegible]
a current is to decompose the mer[illegible]
mercury released to this [illegible]
zinc being dissolved off the positive [illegible]

The electro-motive force of this [illegible]

ceedingly uniform, providing only a high external resistance, not less than 1,000 ohms, is employed. If the resistance of the circuit is low, the current becomes proportionally strong. The mercury salt is not then capable of being decomposed at a corresponding rate, whence polarisation sets in and the electro-motive force falls in consequence. The electro motive force also decreases with an increase of temperature, the rate being about 0·08 per cent. per degree Centigrade.

FIG. 16.



The commercial form of Clark cell constructed after the plan of Dr. Muirhead is illustrated in fig. 16. Instead of using a layer of mercury, the platinum electrode A, fused through the glass-containing vessel, is made of a long piece of wire which is coiled into a close flat spiral and coated with mercury, either by heating and then immersing it in a mercury bath, or by heating the mercury and the platinum together. The spiral is then embedded in the paste, composed of pure mercurous sulphate and a saturated solution of pure zinc sulphate, *p*. The pure zinc rod, *z*, is dipped into the paste, and a cement stopper, *c*, holds the whole firmly together, so that the cell is made more portable than that shown in fig. 15, which has the disadvantage that the constituents of the cell are liable to become mixed if it is not used very carefully. The mercury deposited on the platinum spiral is sufficient to form the negative element or 'plate,' so that a layer of mercury is not really necessary.

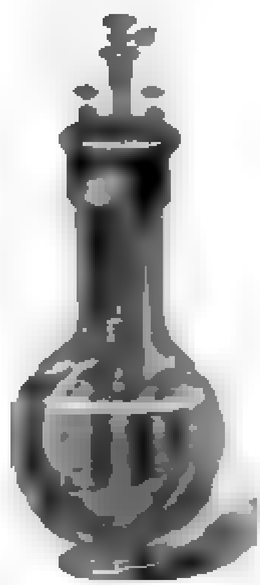
FIG. 17.

Fig. 17 shows the method employed for casing in. A cylindrical brass case with an ebonite cover is used, and contains two cells which can be balanced one

[redacted]

ainst the other to test their relative [illegible] they can be used together and give a [illegible] thermometer is likewise provided, the [illegible] e tube bent so as to lie over the [illegible] important, though simple [illegible] ace of an error due to a varying temperature.

The only other form of [illegible] otice is that in which a solution of bichromate of [illegible] mployed, and which is generally made in the form [illegible] liagram (fig. 18). It consists of an alternation of zinc and carbon plates (always one more of carbon than of zinc) placed in a glass vessel containing the solution. The carbons are all connected with one terminal so as to give a large negative surface, and all the zincs with another to oppose a large positive surface to the solution. In most cases the zincs are attached to a metal rod, a, which slides in a hole in the cover, so that by raising the rod the plates can be readily removed from the [illegible] and the wasteful consumption of the zinc and bichromate of potash which would otherwise take place when the cell is idle prevented.



The solution consists of [illegible] part by weight of bichromate of potash, [illegible] parts of sulphuric acid (of 1·8 specific gravity) [illegible] The bichromate of potash is first [illegible] slowly to the acid, stirring all the time [illegible] bichromate of potash into chromic [illegible] phate, which precipitates in a beautiful [illegible] chemical reactions being indicated by the equation —

$$K_2Cr_2O_7 + 7SO_4H_2 = 2CrO_3 + [illegible]$$

Bichromate of potash. Sulphuric acid. [illegible]

Water is then added slowly, when the [illegible] and the chromic anhydride converted [illegible] acid (H_2CrO_4) by the absorption of water [illegible] being taken up, with the usual result [illegible] sulphuric acid and water—viz. the evolution of a

amount of heat. The energy with which the acid unites with the water is very great, and it is this that necessitates the slow addition of the latter. If poured on too abruptly there is considerable danger of the mixture being ejected from the vessel and scattered about the person or on anything that may be near. As the acid is exceedingly corrosive, it is impossible to take too much precaution when adding the water. In ordinary cases where the acid and water are to be mixed it is by far the safer plan to add the acid to the water, as the former will then find plenty of the latter to satisfy its almost insatiable thirst.

When the solution of the crystals is completed and when the liquid has cooled down to the ordinary temperature, it is ready for use. On completing the circuit and allowing the current to flow, the zinc is dissolved, forming zinc sulphate, and the chromic acid is converted into chromic sulphate, water being liberated. The reaction may be expressed by the equation :—

$$\underset{\text{Zinc.}}{3Zn} + \underset{\text{Sulphuric acid.}}{6H_2SO_4} + \underset{\text{Chromic acid}}{2H_2CrO_4} = \underset{\text{Zinc sulphate.}}{3ZnSO_4} + \underset{\text{Water}}{8OH_2} + \underset{\text{Chromic sulphate.}}{Cr_2 3(SO_4)}$$

This battery has a high electro-motive force, while its resistance is very low. It yields, therefore, a considerable current, which does not, however, last long, rarely more than an hour or so, because of the rapidity with which the cell becomes polarised. On the other hand, when only used occasionally, the same solution will last for a very long time. As there is a tendency, by secondary chemical reactions taking place between the various constituents of the cell, to form hard crystals of a double salt (known as chrome alum) which at times cause a fracture of the jar, it is advisable to avoid square or flat cells for this battery. As we shall presently see, a modification is extensively used on account of its high electro motive force, its low internal resistance, and its approximation to constancy.

We come now to consider the double liquid batteries, the great aim of which is to obtain constancy, even if at the loss of a little power. The chief obstacle to constancy, we have seen, is the accumulation of hydrogen on the negative surface, which hydrogen must therefore be absorbed. Daniell, in 1836, was the first to achieve this object, which he did by using a metallic salt in the

opper, which forms itself into nuggets in the pores of the earthen-are and frequently chip or even completely fracture it.

The zinc should be pure, or as nearly so as it can be obtained. hemically pure zinc, however, is manufactured with great diffi-ulty, and is consequently very expensive. The presence of oreign matter is, nevertheless, a very great deterrent to the good orking of the cell, for it must be remembered that the presence a solution of two metals in contact or otherwise electrically onnected, always results in the production of electrical currents. f, therefore, there are particles of foreign metals mixed up with he zinc, there necessarily occurs local currents which act disad-antageously in at least two ways first by wasting the zinc, and econdly by weakening the main current. As zinc is positive to very available substance (the only metals positive to it being otassium and sodium, which, on account of their extreme affinity or water, are never employed for battery purposes), the admixture f particles, say, of iron, tin, or arsenic, causes small currents to avel from the zinc to these particles, and while the impurities emain to a great extent unaffected (because of their being the egative element), the zinc is constantly suffering a loss by con-umption or conversion into a salt. These minute currents are urthermore produced on the surface of the zinc, and must, as lready mentioned, interfere considerably with the production of he primary current. The difficulties arising from the presence of mpurities are also increased if the zinc is imperfectly or im-properly manufactured. The molecular arrangement (or the elative position of the molecules) must be homogeneous through-out the surfaces of each plate, otherwise currents will be set up etween the softer and harder parts of the zinc in a word, they ossess opposite electrical properties, so that even if chemically pure inc were procured, it would not follow as a matter of course that we should be secured against this source of wasteful local action. Concentrated sulphuric acid has, it may be mentioned, no effect on pure zinc provided it is properly annealed that is to say, that the surfaces have been softened and made molecularly homoge-neous. The acid can, therefore, furnish us with a tolerably reliable test for the degree of purity and equable texture possessed by the metal. So important, indeed, is this question of uniformity that

a difference of temperature will frequently determine a differen
of potential, and therefore cause a current to flow.

The effect both of the presence of any impurity and of un-
equal hardness can, however, be effectually overcome, at least fo
a time, by the process known as 'amalgamation.' This proce
consists in first thoroughly cleansing the surfaces of the metal b
immersing it for a time in a dilute sulphuric or hydrochloric ac
solution, and subsequently (but while still wet with the acid
coating the surfaces with mercury. This operation is generally
recommended to be performed by rubbing the mercury on wi
a sponge or piece of cloth at the end of a stick; but this i
a very irksome and tedious operation, more especially when th
zincs are cylindrical, and it is quite as, if not more, efficacious t
pour the mercury (which should afterwards be used for no othe
purpose) into a flat vessel and lay or roll the zincs in it. Th
may be thought a wasteful process, but the superabundant me
cury can be easily removed by wiping the surfaces over and the
standing them on a dish, to allow any mercury that may be st
free to fall off. This method is much to be preferred when it i
required to amalgamate a large number of plates. A very little mer
cury deposited at the bottom of the zinc division in the batter
will suffice to keep the plate well amalgamated for a long time.

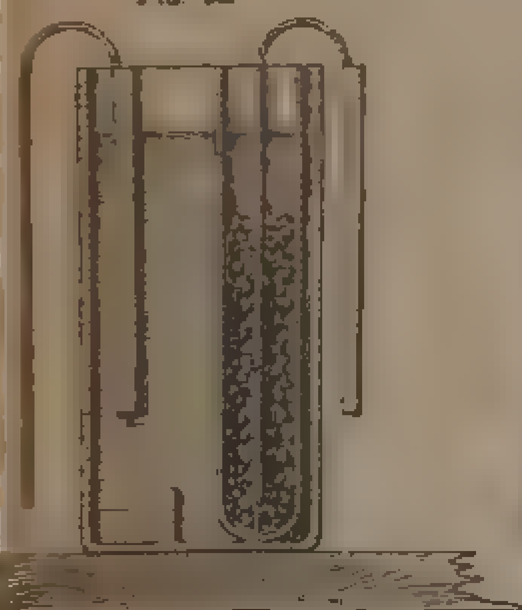
By adopting the process of amalgamation the commonest zin
can be rendered thoroughly serviceable for a greater or less perio
according to the degree of effectiveness with which the proce
has been carried out. As to its rationale, it appears evident th
the function of the mercury is to homogenise the molecul
arrangement by uniformly softening the zinc and forming with it
regular amalgam unassailable by pure sulphuric acid. The amal
gam in an almost liquid state glides over and covers up an
impure particles that have not been dissolved off by the washin
process; as the zinc wears away these particles fall out and dr
to the bottom of the cell to do no further harm.

The mercury does not enter into action with the acid or
any other way interfere with the efficient working of the cell, b
on joining up the battery the acid attacks and dissolves the zin
more or less uniformly, the mercury eating its way inwards as t
superficial zinc particles enter into the solution.

...he circular form of battery [illegible] ...ell or floor space, which [illegible] ...ctica superseded the [illegible] ...are for that reason to [illegible] ...ally introduced by Dr Muirhead. [illegible] ...den box or trough, into which [illegible] ...hite glazed porcelain or ebonite are placed, which [illegible]

...t and compact appearance, as shown [illegible] ...section of one of the single-cell [illegible]

Fig. [illegible]



...ating the double cell form. The latter is [illegible] ...ment. There is a little ridge along the [illegible] ...fig. 20) to keep the flat porous [illegible] ...e vessel containing the copper plate is [illegible]

sulphate crystals, the zinc, which should be not less than ½ in. thick (to allow for waste by local action), being suspended in the zinc sulphate solution. It will be noticed that the copper plate is attached to the zinc of the next adjacent cell. It is usual practice to rivet one end of a copper strap on to the copper plate, the zinc being cast on to the other end of the strap. In this way expensive binding screws or terminals are dispensed with, and good and substantial contact is ensured. The last zinc and the last copper are connected to brass terminals, which become respectively the negative and positive poles of the battery.

Nothing but clean water (hard water should, if possible, be avoided) is poured into the zinc division, but sufficient is added to bring it up to within about a quarter of an inch of the top of the zinc plate. The battery at the end of about twenty-four hours will be found to be in working order, the sulphate having dissolved in the copper division and enough passed through the porous partition to start the chemical action. Under these circumstances, then, a portion of the cupric sulphate that would otherwise be wasted is utilised to convert the water into a solution of zinc sulphate. If the battery is wanted for immediate use, the zinc cell must be filled with a weak solution of sulphate of zinc (or sulphuric acid), and the copper cell with a saturated solution of sulphate of copper; action then commences at once. It is often more convenient to dispense with the trough or box and place the cells side by side on a shelf. The advantage of this in an extensive battery room is apparent.

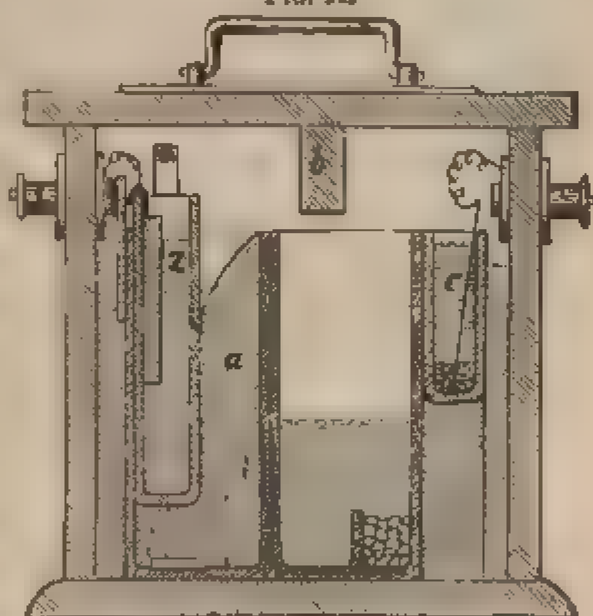
All porous pots should be dipped, top and bottom, in melted paraffin wax, so as by filling up the pores to prevent the solutions mingling too freely or rising to the top above the level of the liquids, and so allowing the water to evaporate and the salts to crystallise out. One side of the flat porous pots may also be paraffined with advantage, viz. the side which is remote from the zinc.

A porous pot which has been once used should not be allowed to get dry, as the crystals which form on drying chip it, and soon render it useless.

The Daniell cell, when in good condition, can be employed as a standard of electro-motive force, and owing to the ease

ch the copper salt is decomposed, the cell possesses one great antage over the Clark standard cell, in that it does not polarise en joined on short circuit, even when it is giving a more or less tinuous current. It has, however, the disadvantage that for urate measurement it requires a certain amount of attention ich must be particularly directed to the zinc division, to keep it e from copper. A very handy and convenient form of Standard niell is that shown in fig. 22. In a square wooden box, pro- ed with two terminals for nection, are three water- ht chambers. When the is not in use, the copper e *c* is removed to the ht-hand chamber contain- copper sulphate solution, zinc plate z and the porous containing it being trans- ted to the left-hand cham- . This porous pot is plied with a semi-satu- d solution of zinc sul- te, the copper sulphate tion and its reserve of tals being placed in the middle chamber. All that is then essary to place the cell in working order is to remove the copper the porous pot into the centre division. The stud *b* attached the lid, prevents it being shut down unless the porous pot has n removed to the outer chamber. Such a cell will maintain an tro-motive force of 1·07 to 1·079 volts for a considerable time, viding that the copper and porous pot are removed to their pective idle chambers, between the tests.

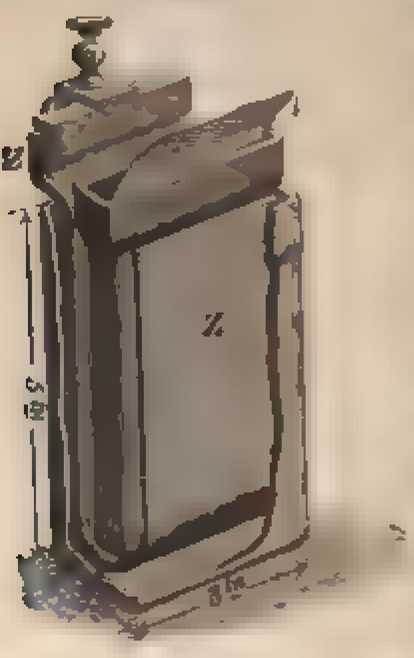
FIG. 22.



We have seen that Daniell absorbed the freed hydrogen by sing it to reduce a metallic salt: Grove and Bunsen in their teries oxidised the liberated hydrogen by means of an acid, er being produced by this hydrogen instead of sulphuric acid, n the Daniell. In the negative division concentrated nitric is used, into which Grove dipped platinum foil, while Bunsen pted gas-carbon. Zinc, as usual, constituted the positive plate

in each case, the liquid placed with it being a solution of sulphu acid. The diagram (fig. 23) shows the construction of the Gro It is usually contained in a flat rectangular glass, porcelain, ebonite vessel, porcelain being perh the best. The amalgamated zinc pla Z, is bent into a U shape, and suppo the flat porous pot which contains t platinum foil, P. By this arrangeme each surface of the platinum has o posed to it a surface of zinc, the inter resistance being consequently very lo A strong solution of sulphuric ac (about 1 of acid to 7 or 8 of water) poured into the outer cell and stro nitric acid having a specific gravity 1·420 is placed in the inner cell wi the platinum. The copper or br connections or terminals should be la quered except upon those surfaces whi take part in the electrical circuit, to protect them as much possible from the gases which are evolved during the working the cell.

FIG. 23.



The action is in the first stage similar to that in the Dani but there is some diversity of opinion as to what actually tra pires in the platinum division. Zinc sulphate is formed by t action of the sulphuric acid on the zinc, and the hydrogen whi is thereby released reduces the nitric acid (HNO_3) to water a nitric peroxide (N_2O_4), which ascends as a gas into the air. T gas is distinguishable from all others by its dense brown appe ance and its extremely pungent odour.

The chemical reactions may be represented by the equatio

$$Zn + SO_4H_2 + 2HNO_3 = ZnSO_4 + 2OH_2 + N_2O_4.$$

It will be noticed that the acid, which, to give the maxim strength of current, should be concentrated, must be serio weakened as the current is produced. This results, in the f place, from the fact that every atom of hydrogen set free from sulphuric acid decomposes a portion of the nitric acid, while

e the water which is formed dilutes and so weakens
acid. The zinc which [illegible]
colourless [illegible]
or less soluble in the acid [illegible]
it is practically useless.

n cell, which is [illegible] in fig. [illegible]
in the circular form. The outer [illegible]
glass, and con-
of sulphuric acid,
he proportion of 1
8 of water. In
Into this is placed
cylinder, and inside
ous cell, containing
bon, immersed in
acid. The porosity
enables it to pre-
id a very extended
ompared with the
e Grove cell.

in the battery is
e same as in the
the carbon and
ain chemically un-

ll and the Grove cells are the representatives of two
es of battery. Daniell's has attained its high standard
on account of its cheapness and its constancy. It
constant than either of those we have as yet [illegible]
Grove, on the other hand, is very powerful, but
larisation, it runs down very rapidly, and is not
ore than three to four hours at a time. It is, how-
nt to remember that if the negative plate and [illegible]
rom the cell separately and allowed to [illegible]
can be used again and the cell will give
good as before. The same acid can be
before it is so reduced in strength as t
ent, a state which, as already mentioned,

by the greenish hue imparted to the acid. The chief use of the Grove cell in England is for experimental purposes. It has the advantage that it is very compact and portable. The Bunsen has a slightly higher electro motive force, and it is somewhat cheaper than the Grove. As, however, it is generally constructed in the cylindrical form, it is much less convenient.

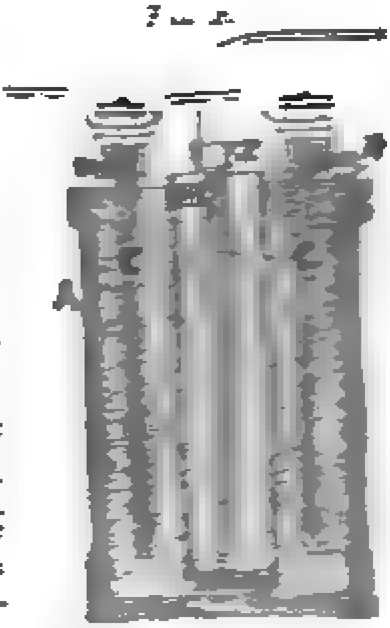
There are many forms of double-fluid bichromate batteries. In nearly all of them zinc and carbon are employed for the positive and negative elements respectively, the difference being, generally speaking, confined to the depolarising solution surrounding the carbon plate. In one of them, however, a great feature is made of the means adopted for keeping the zinc well amalgamated. This cell is known as the 'Fuller,' and it is usually put up in a round earthenware jar, in which is placed a comparatively small porous pot containing a zinc rod of peculiar shape, as shown in fig 25. The zinc is cast on to a stout copper wire which passes almost to the bottom of the rod and helps to keep it intact. Two or three ounces of mercury are placed in the porous pot, which, on the addition of the solution (dilute sulphuric acid), creeps up the surface of the zinc by the force of capillary attraction and so keeps it uniformly and automatically amalgamated. A small carbon plate is placed in the outer vessel in a solution of bichromate of potash, derived, however, from a stiff paste, of which a quantity is placed in the bottom of the cell, and which contains, probably, a quantity of free chromic acid, soda nitrate, &c. An unusually large quantity of this solution is generally provided in order to maintain its strength for a longer period of time than would be the case were the more usual proportions adopted. The chemical action is practically the same as that in the single-fluid bichromate cell. What is true of the nitric acid cells of Bunsen and Grove is also true, although, perhaps, to a less degree, with each and every form of bichromate of potash or of chromic acid cell—viz. that polarisation and the accompanying

FIG. 25.

[redacted]

n the electro-motive force, and therefore ... the
ngth, sets in after the battery has been in use for a
nore or less. The electro-motive force of the cell is
gh, ranging from 1·9 to 2·25 volts. Its internal resist-
very low, whence it finds considerable ...
st ingenious battery yet constructed for ...
probably that of Mr. A. Rene Upward, the ...
be gathered from figs. 26 and 27. The positive plate
ist zinc immersed in water
wards becomes zinc chloride
in the porous pot, B. The
ement consists of two carbon
joined together and placed in
essel, A, of glazed earthenware,
between A and B being then
ked with crushed carbon and
with a layer of cement ...
gas, which has considerable
zinc, is led into the tube ...
e, D (fig. 27), and passing
e small pieces of carbon ...
to the zinc division, where ...

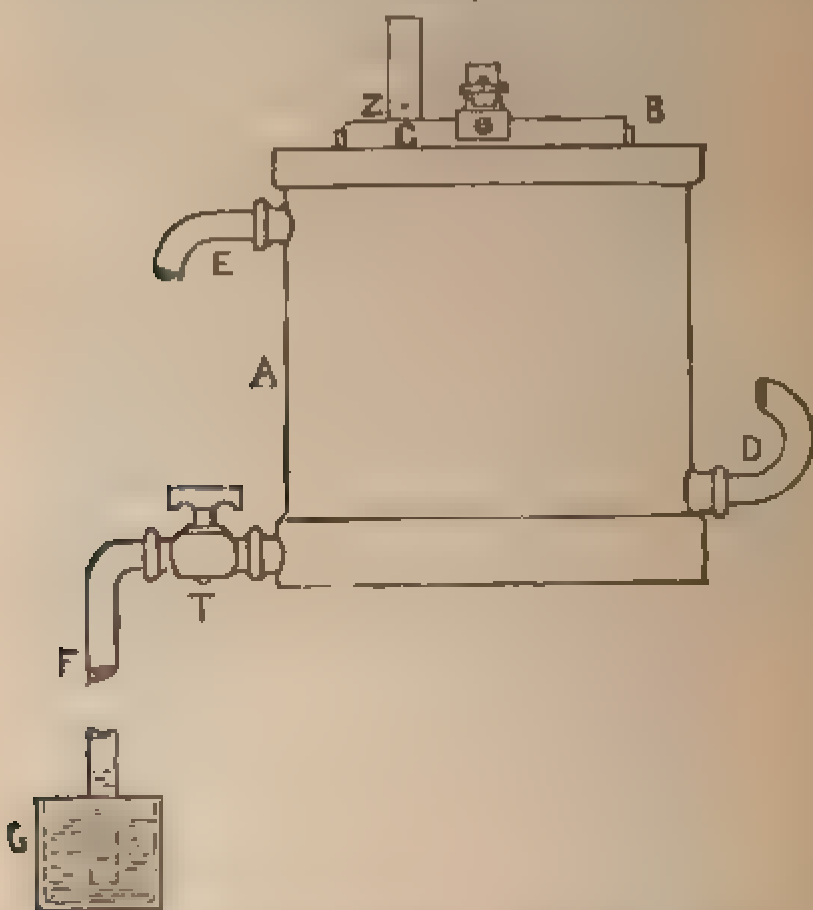
Fig. 26.



ctly into chemical union with the ...
hus $Zn + Cl_2 = ZnCl_2$ ...
the one cell passes through the ...
the next cell. As the ...
e porous partition it accumulates ...
om of the outer vessel and thence ...
flows through the tube ...
r, always sufficient water ...
tube E to prevent ...
ell, measuring ...
internal resistance ...
ative force of ...
ter form each cell ...
o as to give a large positive surface, the ...
of eight carbon plates. The other details
shown in figs. 26 and 27. ...

direct to the apparatus in which the chlorine gas is generated, the outlet tube being connected to the inlet of the next cell, the outlet of which is in its turn connected to the bottom of the first of a series of vertical columns, made by carefully sealing together a number

FIG. 27.



of ordinary earthenware drain pipes.[1] The top of the first of these columns is connected to the bottom of the second, and so on, the top of the last of the series being provided with an outlet tube extending into the outer air. Chlorine gas is rather more than twice as heavy as air, so that as the gas first enters at the bottom of the cells it drives out the superincumbent air by ordinary displacement. Similarly with the reservoir columns, the first being filled with chlorine before any enters the second column, and so on. The connecting tubes are of lead, which is the most

[1] In the earlier form of the battery, a very pretty and ingenious aspirator was connected to the battery which served the purpose of drawing the gas through ... required.

[redacted]

ible material available, as it has only a feeble affinity for rine at ordinary temperatures. A piece of glass tubing is let each of the lead pipes connecting the reservoir columns, and, back of the glass being painted white, the presence of the rine is easily recognised by its distinguishing greenish-yellow

There are various ways of generating chlorine, the method loyed by Mr. Upward being that of heating a mixture of ganic oxide, sulphuric acid, and brine (sodic chloride). The tion is represented by the equation :—

$$O_2 + 2SO_4H_2 + 2NaCl = SO_4Na_2 + SO_4Mn + 2OH_2 + Cl_2$$

anic le.	Sulphuric acid.	Sodic chloride.	Sodic sulphate.	Manganous sulphate.	Water.	Chlorine.

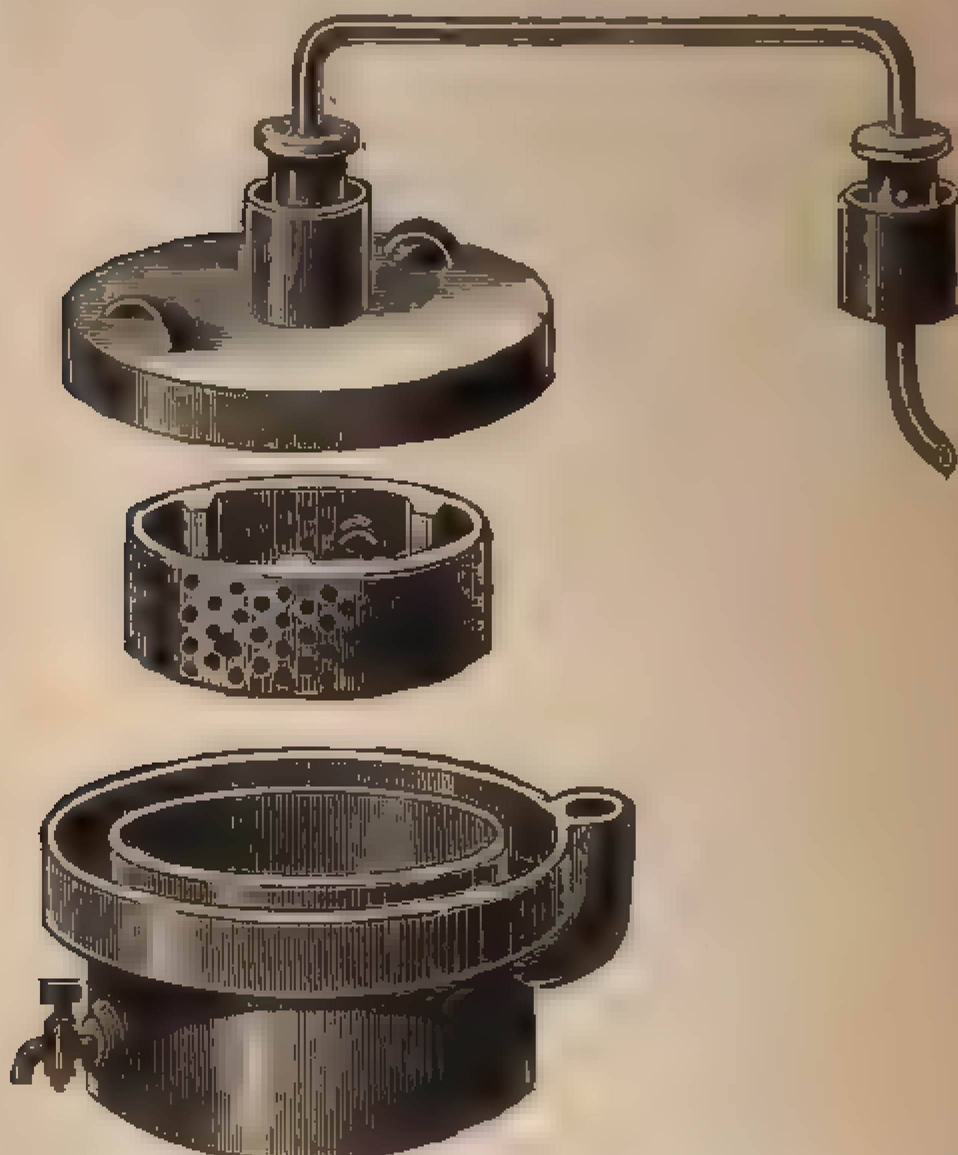
The whole of the chlorine contained in the salt is thus reduced ie gaseous state.

The apparatus employed for the generation of the gas is illus- :d in fig. 28. In a round earthenware pan is placed the perfo- d earthenware tray previously filled with the black manganic e, sufficient for two or three weeks' run. The cover is then ed in position and sealed with water run into the groove vn in the pan. The brine and acid, which are stored in jars, supplied daily through the inlet tube shown on the right of pan, the spent liquid being drawn off at the tap on the left, :h is connected directly with the drain by means of a sealed . The whole being placed in a sand bath, sufficient heat is lied by a small gas jet or oil flame to bring about the required nical changes. The gas is conveyed by the tube shown at top to the first of the battery cells. When it is required to iarge the retort with manganic oxide, it is flushed out with :r (entering at the same aperture as the acid) to remove any : of the chlorine gas. The lid and tray of spent oxide taken out and a spare tray filled with fresh oxide inse the lid replaced.

These cells might be joined up in a sufficiently long serie : a number of incandescent lamps directly, but that nun ld be limited owing to the comparatively high inter : of the battery. It is suggested, therefore, to em ple of cells, and with them to charge, one by on

of secondary cells (see Chapter XIV.), the primary current being automatically switched from one cell to the next, after it has been charging it for a certain time. Clever in conception as this battery

FIG. 28.



undoubtedly is, it is scarcely one that could be placed in the hands of inexperienced people, or be relied upon to maintain an electric light installation for any length of time. Chlorine gas, again, is very insidious, and its occasional escape in greater or less quantities could hardly be prevented. Were it perfect, however, there would only be a limited field open for its employment, and that on a very small scale. Its expense would prevent it ever entering

[redacted]

to competition with the dynamo machine for work on a large ale.

There are, of course, a vast number of cells which we have not nsidered it necessary to describe here, but they may generally placed under one or other of the typical heads, viz. the Daniell th a metallic salt, or the Grove with an acid, in the negative divi- on. The general difference is that the latter polarises more or less pidly, while the former does not polarise, but is kept constant by e metallic deposit upon the negative plate.

Primary batteries are of but little service in electric light- g. They are, of course, valuable for testing purposes, but as urces of current for the electric light they are altogether out of ace, except for small isolated work, owing to the fact that zinc, hich is in every case used as the positive plate, and which, being onsumed in the generation of the current, corresponds to the oal consumed in an engine, is very many times dearer than coal. Even were expense a question of minor importance, there still emains the fact that primary batteries are very troublesome to naintain, and more often than not give off noxious fumes, which are also as a rule highly corrosive. What is really wanted, putting aside altogether the question of expense, is some simple form of cell, of which the constituents can be easily obtained and replaced; from which no injurious fumes can arise; which shall have a high electro-motive force and a low internal resistance, and be fairly constant withal.

There are three considerations that have to be taken into account when determining what kind and what number of cells it would be most advisable to employ for any particular purpose— viz. the relative constancy and electro-motive force, and the ratio between the internal resistance of the cell and the external resist- ance, or the resistance of the connecting wires and apparatus. It will have been gathered that there is in this matter of electr motive force and constancy considerable variation. We will n enter here into the matter of expense, for in the end that which the best cell for any particular purpose generally proves to be al the cheapest. The internal resistance is, however, an im factor. If it were negligible, it would, for example, be pc maintain a current of one ampere by one Daniell cel

through an external resistance of one ohm, for as (see Chapter II.)

$$C = \frac{E}{R}, \text{ then } \frac{1 \text{ volt}}{1 \text{ ohm}} = 1 \text{ ampere.}$$

But the average Daniell cell offers four ohms resistance, so that the current, where R is the external resistance of one ohm, and r the internal resistance, would be

$$\frac{E}{R + r} = \frac{1}{1 + 4} = \cdot 2 \text{ ampere ;}$$

and if we were to attempt to increase this current materially by the addition of, say, nine other similar cells, we should fail, for then

$$\frac{10E}{R + 10r} = \frac{10}{1 + 40} = \cdot 25 \text{ ampere nearly.}$$

Similarly, with 100 such cells through this unit resistance--

$$\frac{100E}{R + 100r} = \frac{100}{1 + 400} = \cdot 25 \text{ nearly.}$$

We see, then, that increasing the number of cells in this way, when the external resistance is low, produces no correspondingly good effect, for the simple reason that, although we might proportionally increase the electro-motive force by so doing, we should at the same rate increase the circuit resistance. As a matter of fact, no ordinary Daniell cell or battery can possibly develop a current of one ampere, its internal resistance being too high.

On the other hand, were we to employ Grove cells (which for simplicity we will assume to have an electro-motive force of 2 volts per cell), the advantage of increasing the number of cells on a low resistance circuit soon becomes apparent. For example, with an external resistance of 1 ohm and an internal resistance of ·2 ohm per cell, one cell would give us,

$$\frac{E}{R + r} = \frac{2}{1 + \cdot 2} = 1 \cdot 6 \text{ amperes.}$$

Two such cells would produce

$$\frac{2E}{R + 2r} = \frac{4}{1 + \cdot 4} = 2 \cdot 85 \text{ amperes.}$$

And three cells

$$\frac{3E}{R + 3r} = \frac{6}{1 + \cdot 6} = 3\cdot 8 \text{ amperes nearly.}$$

Similarly, four cells would give 4·4 amperes and five cells would yield 5·0 amperes. But from ten cells we should only get

$$\frac{10E}{R + 10r} = \frac{20}{1 + 2} = 6\cdot\dot{6} \text{ amperes.}$$

While with 100 such cells the current would be

$$\frac{100E}{R + 100r} = \frac{200}{1 + 20} = 9\cdot 5 \text{ amperes,}$$

showing again that as the internal resistance approaches or exceeds the external, the proportional current from the battery is reduced. When, however, the external resistance is relatively high, say 1,000 ohms, the battery resistance becomes proportionally low, and, therefore, to a certain extent, negligible. The current from one Daniell cell would be

$$C = \frac{E}{R + r} = \frac{1}{1000 + 4} = \cdot 000996 \text{ ampere.}$$

With ten cells we should get,

$$\frac{10E}{R + 10r} = \frac{10}{1000 + 40} = \cdot 00961 \text{ ampere,}$$

or, practically, a current of tenfold strength.

Similarly, with a battery of 100 cells, we should get

$$\frac{100F}{R + 100r} = \frac{100}{1000 + 400} = \cdot 0714 \text{ ampere.}$$

Again, one Grove cell would give through 1000 ohms

$$C = \frac{E}{R + r} = \frac{2}{1000 + \cdot 2} = \cdot 002 \text{ ampere,}$$

and ten cells would give

$$\frac{10E}{R + 10r} = \frac{20}{1000 + 2} = \cdot 0199 \text{ ampere.}$$

From 100 cells we should get—

$$\frac{100\text{E}}{\text{R} + 100r} = \frac{200}{1000 + 20} = \cdot 196 \text{ ampere.}$$

With either the Daniell or the Grove the strength of the current increases in almost the same ratio as the number of cells when the external resistance is high. But as the Grove is vastly inferior to the Daniell in constancy, and as it is a very expensive form of battery, the deduction is that Daniell cells should be used for circuits of high resistance, compensating for their lower electro-motive force by a corresponding increase in numbers. On the other hand, the Grove, in consequence of its low internal resistance, is better adapted for circuits of low resistance.

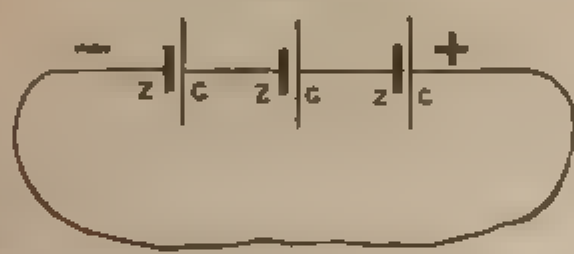
The internal resistance, however, of different cells of any particular type varies inversely as the size of the plates (counting only the active or opposed surfaces). It also varies directly as the distance between them (making due allowance for the resistance of the porous pot, which would, of course, have a constant value unless varied in size or thickness). The meaning of this is plain, for if we were to double the size of the plates we should halve the resistance and proportionally increase the current strength.

The same object is attained by joining cells in 'parallel.' So far we have only considered them as joined in series, that is to say, the copper of one cell joined to the zinc of the next and so on. Under such circumstances the electro-motive force of the battery is equal to the sum of the electro-motive forces of the various cells. If the coppers of two cells are joined together, and likewise the zincs, and the two junction wires connected to the external circuit, a current will be developed by an electro-motive force equal to that of one cell, the joint resistance of the two equal cells being half that of one of them used separately. The arrangement is, in fact, equivalent to doubling the size of the plates.

This will, perhaps, be made clearer by a reference to the diagrams, figs. 29, 30, and 31. Fig. 29 represents a battery of three cells joined in series, the short thick strokes representing the zinc or positive plates, and the long thin ones the copper or negative plates. Fig. 30 shows two cells joined up in parallel. If they are both of exactly the same electro-motive force, no current can

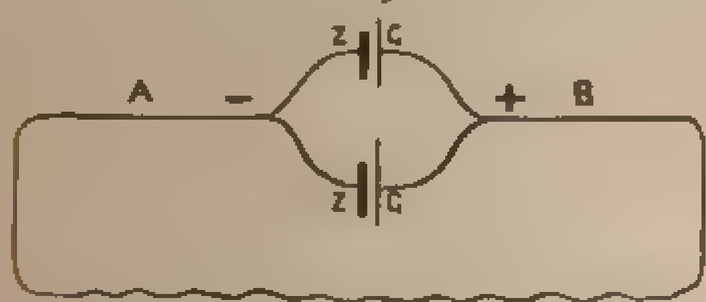
flow from C to C or from Z to Z, but on joining the external wires A and B together, a current would be generated by each cell and

FIG. 29.



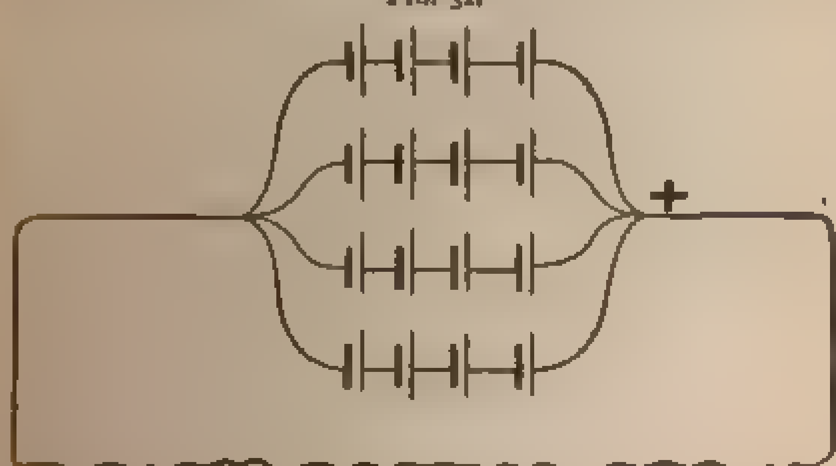
pass through the external circuit from B to A. As already stated, the joint resistance of these two cells would be half that of one

FIG. 30.



of them. With a low external resistance the current strength would be increased proportionally. In fig. 31 are shown sixteen

FIG. 31.



cells divided into four sets of four cells each, the sets being joined up in parallel. On completing the external circuit a current will flow, having an electro-motive force equal to that of four cells,

but the battery resistance will be only one fourth of that of four cells.

The joint resistance of any number of parallel batteries is equal to $\frac{rs}{\text{B}}$, where r is the resistance per cell, s the number of such cells joined up in series in each individual battery, and B the number of such batteries joined together in parallel. This is simply an application of the law that with a number of conductors, N, of uniform resistance, R, joined together in parallel, their joint resistance is equal to $\frac{\text{R}}{\text{N}}$. For rs is the total resistance of each of the batteries joined together in parallel. This arrangement is sometimes very advantageous; for example, if sixteen Daniell cells, each of 1 volt electro-motive force and 4 ohms internal resistance, are employed in series for a circuit of 4 ohms external resistance, the current will be

$$\frac{16}{4 + 64} = \cdot 235 \text{ ampere} \quad . \quad . \quad . \quad (1).$$

By dividing the cells into two sets of eight cells each and joining these in parallel, the current is increased, thus

$$\frac{8}{4 + 16} = \cdot 400 \text{ ampere} \quad . \quad . \quad . \quad (2).$$

On rearranging the cells, as shown in fig. 31, the current becomes

$$\frac{4}{4 + 4} = \cdot 500 \text{ ampere} \quad (3).$$

Pursuing this plan any further, however, results in a diminution of the current; for example, if eight sets of two cells each are joined in parallel, we get

$$\frac{2}{4 + 1} = \cdot 400 \text{ ampere} \quad . \quad . \quad (4).$$

While with the whole of the sixteen cells joined in parallel we get only

$$\frac{1}{4 + \cdot 25} = \cdot 235 \text{ ampere} \quad . \quad . \quad (5).$$

With circuits of comparatively low external resistance there is, therefore, a best possible arrangement of the cells to give the

strongest possible current, and with any given number of cells this arrangement is arrived at when the internal resistance is equal to the external, or when $R = \frac{rs}{B}$.

Such an arrangement is not, however, economical; nor, indeed, is any arrangement, unless the external resistance is considerably in excess of the internal. As has been already stated, the strength of the current is the same in all parts of the circuit, consequently in (1) sixteen times as much zinc, &c., is consumed in the sixteen cells as would be consumed in a single cell capable of maintaining an equal current. In (3), however, each set of four cells must be considered as a separate or branch circuit, and only one-fourth of the current flowing in the external circuit would flow through each of these separate sets. The external current is approximately twice as strong as in (1). Therefore the individual current in each cell and the consequent consumption of zinc is only half as great. In (5), where there are sixteen cells in parallel, a current is produced equal to that resulting from a battery of sixteen cells in series, but, the cells being joined up in parallel, only one sixteenth of this current flows through each cell, so that the total consumption of zinc in the sixteen cells is equal to that in but a single cell in (1), clearly demonstrating the advantage, from an economical point of view, of using batteries much lower in resistance than the wire or apparatus through which the current has to flow.

One important feature concerning the proportion between the gross electro motive force of the battery and the difference of potential it can maintain in any given external circuit requires careful consideration, for it is a feature that is frequently lost sight of. It was pointed out in Chapter II. that in any given circuit the fall of potential varies directly as the resistance, so that in (1), where the internal bears to the external resistance the proportion of 16 to 1, only one-seventeenth of the 16 volts developed by the battery is available in the external circuit, the remaining sixteen-seventeenths being absorbed in overcoming the resistance of the battery. In (3) the resistances outside the battery being equal to that inside, the electro-motive force of 4 volts developed is halved, 2 volts being available for the external circuit. Similarly in (5), the available electro motive force for the external circuit is sixteen-

seventeenths of a volt (the gross electro-motive force developed being 1 volt), or equal to that produced by the sixteen cells joined up in series, as in (1), where, as already shown, the consumption of materials is sixteen times as great, and, speaking generally, we may say that

$$P = E \frac{R}{R + r}.$$

Where E is the electro-motive force developed by the battery, R is the external resistance, r is the internal resistance, and P the available potential difference at the terminals of the battery. For example, with a battery, as in (4), whose internal resistance is 1 ohm working through an external resistance of 4 ohms, and having an electro-motive force of 2 volts, the available potential difference will be

$$P = 2 \frac{4}{4 + 1} = 1{\cdot}6 \text{ volts.}$$

The available potential difference can also be ascertained in another way which does not involve the necessity for ascertaining the external resistance. Ohm's law declares $C = \frac{E}{R}$ or, $E = CR$. And this is true either of a complete circuit or simply of a part of a circuit. If, for instance, in a circuit of known or unknown resistance the current strength is found to be, say, 1·5 amperes, and that a portion of the circuit offers a resistance of 3 ohms, then the fall of potential, or the electro-motive force absorbed, in that portion of the circuit will be

$$E = CR = 1{\cdot}5 \times 3 = 4{\cdot}5 \text{ volts.}$$

If the known resistance is that of the battery (r), it follows that 4·5 volts will be the electro-motive force absorbed by the battery, and if that is deducted from the total electro-motive force developed (say, 20 volts), the remainder will be the available potential difference for the external circuit, or

$$P = E - Cr = 20 - (1{\cdot}5 \times 3) = 15{\cdot}5 \text{ volts.}$$

Occasion sometimes arises for substituting one form of battery for another without making any appreciable change in the current strength. If the internal resistance were negligible, this would, of

course, be a matter of no difficulty; but even when it is requisite to make allowance for the battery resistance, a simple formula can be employed to ascertain the number of cells necessary to develop a given current strength. For example, suppose that a battery of 100 cells, with an electro-motive force of 1 volt and an internal resistance of 4 ohms per cell, sends a current through an external resistance of 400 ohms, then the current will be

$$\frac{100\text{E}}{100r + \text{R}} = \frac{100}{400 + 400} = \cdot 125 \text{ ampere.}$$

Substituting some other form of battery with an electro-motive force of 2 volts and an internal resistance of 1 ohm, and letting n be the number of such cells necessary to develop 0·125 ampere, then

$$\frac{n2}{n \times 1 + 400} = \cdot 125 = \frac{1}{8} \text{ ampere,}$$

that is to say,

$$\frac{2n}{n + 400} = \frac{1}{8},$$

or,

$$16n = n + 400$$

$$15n = 400$$

$$n = \frac{400}{15} = 26 \cdot \dot{6}.$$

Twenty-seven of these 2-volt cells would maintain in the circuit a current of

$$\frac{27\text{E}}{27r + 400} = \frac{54}{27 + 400} = \cdot 126 \text{ ampere.}$$

Twenty-six cells would be insufficient for the purpose. This formula also possesses the advantage of providing the same potential difference at the terminals of the battery, as well as that of furnishing the number of cells necessary to develop an equally strong current.

CHAPTER IV.

MEASUREMENT OF CURRENT STRENGTH.

HAVING in the preceding chapters shown how a current of electricity can be generated and maintained, and having also explained the various units by which we can measure that current, as well as the resistance, and the pressure or electro-motive force which maintains the current, it behoves us now to turn our attention to the methods of making such measurements and the consideration of the laws involved. In order to make the student's progress at this difficult stage as easy as possible, we will approach the subject experimentally.

If a wire, A B (fig. 32), carrying a current is brought near another wire, C D, also carrying a current, it is found that there is

FIG. 32.

a decided action between the two wires. If the currents are flowing in the same direction, as shown by the arrow-heads in fig. 32, the wires are attracted one to the other. On the other hand, if the currents travel in opposite directions, as in fig. 33, repulsion ensues.

FIG. 33.

The force of this attraction or repulsion depends, among other considerations, upon the strength of the current. It would be

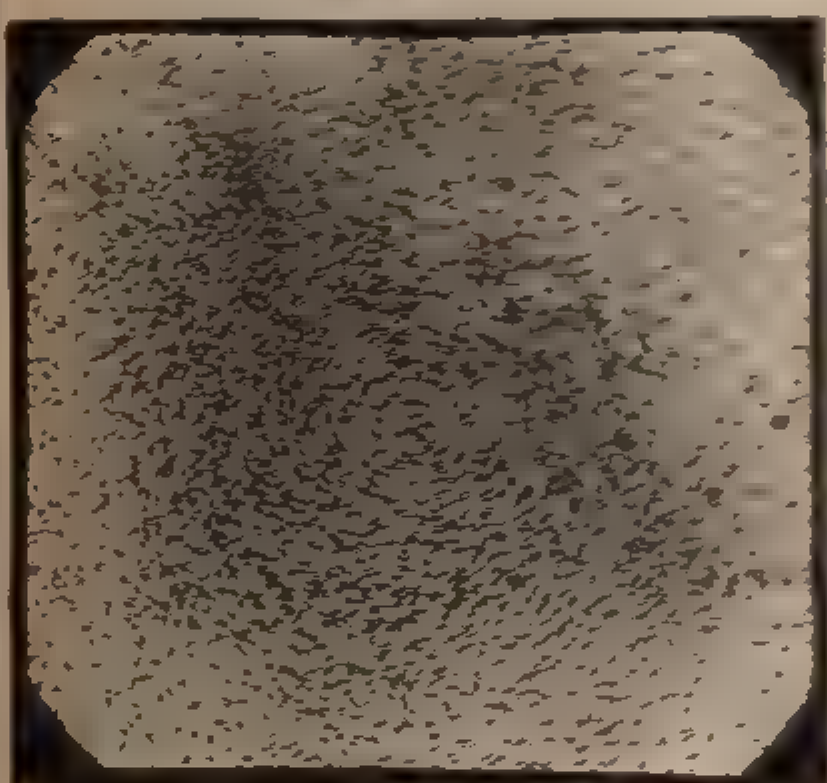
[illegible], therefore, [illegible] of estimating [illegible] doing will be described presently.

[illegible] it is [illegible] wires without the [illegible] force. This [illegible] stresses in the [illegible] which a body [illegible] electricity, and [illegible]

[illegible] though it is [illegible] it is easy to show [illegible] acts.

[illegible] we thread a wire [illegible] cardboard, and [illegible]

Fig. [illegible]

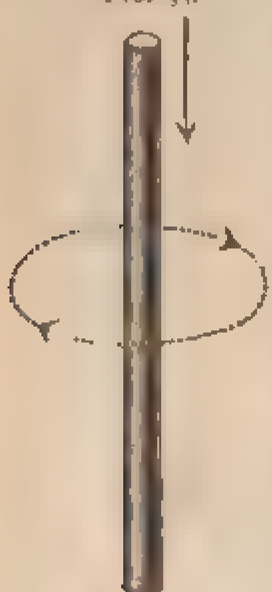


[illegible] themselves in concentric circles round the wire as shown [illegible] 34. This arrangement is caused [illegible] may be observed at any part of the wire. The line

marked out, which show the direction in which the force due to the current acts, are called 'lines of force.'

As in the case of the imaginary lines considered in Chapter I., it is necessary to assume for them a certain direction. That direction along a line of force, indicated by the arrows in fig. 35, is called the 'positive' direction. The direction can be impressed upon the memory by thinking of the act of using a corkscrew. If the longitudinal direction of the screw, either *into* or *out of* the cork, be taken to represent the direction of the current, then the positive direction of the lines of force will be that in which the handle rotates, so that if in fig. 35 the downward direction of the current were reversed, the positive direction of the lines of force would be in the opposite direction to that indicated by the arrow-heads. The space around the wire in which the effect of the current is perceptible is called an 'electro-magnetic field,' and it is important to remember that the strength of this field is exactly proportional to the strength of the current producing it. It extends from the axis of the wire as a centre throughout the surrounding space, but as the distance from the wire increases, the effect is weakened until it at last becomes so feeble as to be imperceptible. The lines of force traversing this field obey precisely the same laws as those laid down for the lines due to a static charge, and the interaction between two sets of lines of force can always be predicted by remembering that their universal tendency is to coincide in direction and to shorten themselves

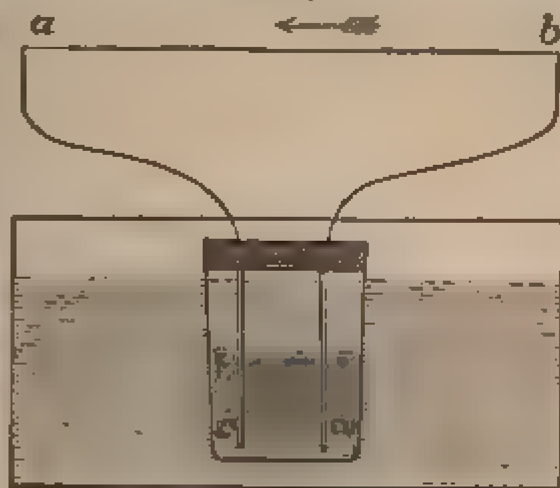
FIG. 35.



Reverting to the experiment with the two wires carrying the currents, it may be said that the force exerted between them always tends to move them so that they shall take up such a position that the currents flow in the same common direction (as in fig. 32) and that the wires as nearly as possible coincide. To prove this, it is necessary to allow at least one of the wires to be ble of moving freely and with as little restraint or friction as le. This can be done by means of a simple device for ucting a movable or floating battery cell. Let a cork be

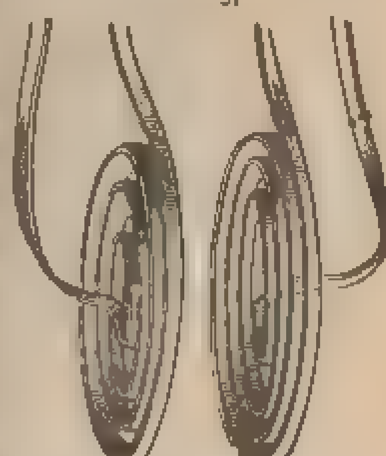
fitted to a small glass beaker partly filled with diluted sulphuric acid, and through the cork pass wires carrying thin strips of zinc and copper or silver, completing the circuit externally by means of a stiff but not too heavy piece of wire, as shown in fig. 36. The small beaker cell can then be placed in a larger beaker, or any other convenient vessel full of water, and, unless too much acid solution has been placed in the smaller beaker or the solid portions are made unnecessarily heavy, the cell will float readily upon the water. If a wire carrying a strong current is placed parallel to the straight part of the wire, *a b*, so that the currents flow in opposite directions, the wire *a b* will be repelled, and, the cell floating away, will turn completely round, so that the currents flow in the same direction; it will then be attracted until *a b* lies as near as possible to the other wire.

FIG. 36



These effects may be increased by increasing the length of the wires, but very long straight wires would be cumbersome and, in fact, impracticable. It is, therefore, more convenient to coil them up into flat spirals (fig. 37), covering the wire with silk, cotton, or some insulating material, to prevent adjacent convolutions getting into contact. The effect between the spirals will be identically similar to that between the same two wires straightened out. For many purposes, however, it is preferable to coil the wire into a long spiral or helix. In fig. 38 one of the helices, A B, is floated in a manner similar to that adopted in fig. 36, the other helix, *a b*, being placed near it. The action between two such helices is very decided, and, being of exactly the same character as that between the straight wires

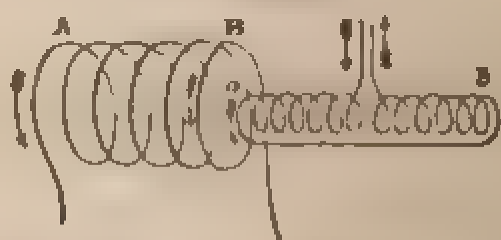
FIG. 37



or flat spirals, may be predicted by remembering the laws we have just stated.

If the currents are flowing in opposite directions round adjacent ends of the spirals or helices, repulsion will take place, and the floating helix, moving more easily than the other, will recede, and, turning completely round on its vertical axis, will approach with its opposite end to the fixed spiral, as in fig. 38. The currents

FIG. 38.



will then be flowing in the same direction, and the floating helix being comparatively large and its movements not restricted, it will not come to rest until it has threaded itself on to or over the other spiral. Such a spiral or helix of wire acts as if the force resided at its extremities, which are termed its 'poles,' and it is for this reason that this form of spiral is called a solenoid.

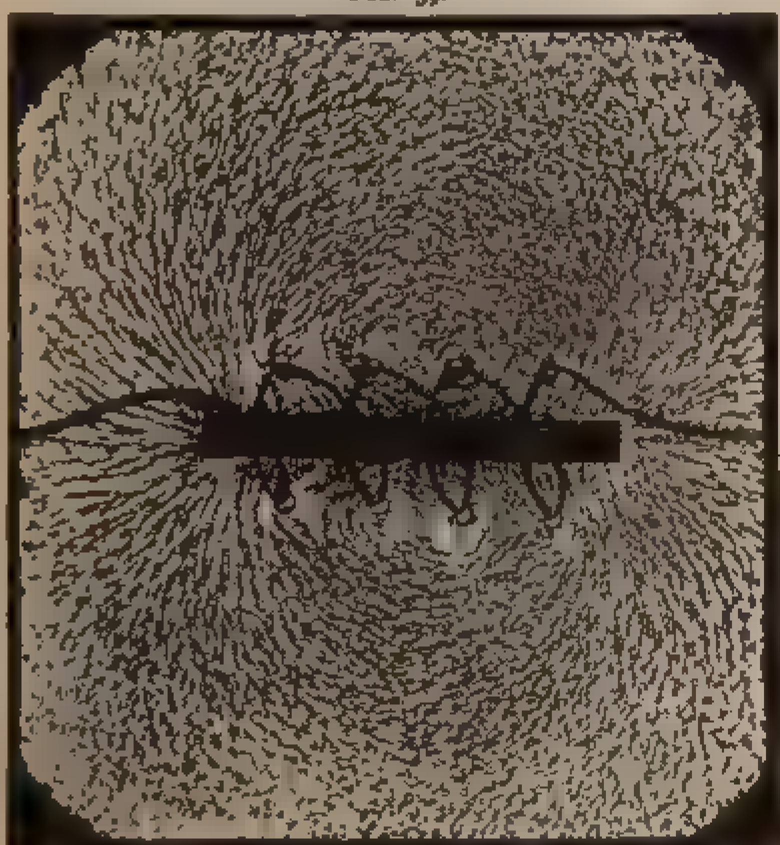
Now the strength of an electro-magnetic field may be measured by the density of its lines of force or the number contained in a given area. From the experiment shown in fig. 34, it is clear that the lines are much denser near the wire than at a distance from it. This is also the case when the wire is coiled up into a helix. The greater part of them there form little circles, closely embracing the wire from which they are generated, and comparatively few of these circles of force pass through the space at the ends or poles of the solenoid, where the force, generally speaking, appears to be concentrated. It will be evident that if we can by any means divert the circles of force so as to compel more of them to pass through the ends of the solenoid, then its effective strength will be greatly increased.

Experiment has demonstrated that iron offers a far easier path for these lines of force than the air does—so much easier, in fact, that they will alter their circular shape and extend a considerable distance from their respective portions of the wire in order to pass

through a piece of iron. This affords us a ready means of leading the lines to, and concentrating them at almost any point we please. It may be mentioned that the relative facility with which the lines of force are propagated by good soft iron, or the electromagnetic conductivity of the iron as compared with that of air, may be as high as 20,000 to 1.

If, then, we place a bar of iron inside a solenoid, a large percentage of the lines of force lose their circular form, and, passing

FIG. 39.



through this iron 'core' (as it is called), they leave it at its ends to complete their excursion round the wire from which they were generated. An example of this action of iron is shown in fig. 39,[1] which illustrates the field developed by a powerful current travelling through a solenoid of a few turns, having a core of compara-

[1] We are indebted to the proprietors of *Engineering* for permission to reproduce figs. 39 to 42.

tively small dimensions. Were a larger or more massive core to be introduced, even more of the lines of force would extend themselves through the iron instead of circulating in the immediate vicinity of the wire.

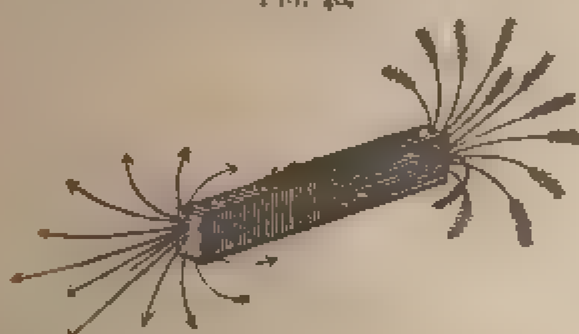
Fitted with these iron cores, the strength of the action between two solenoids is enormously increased. But here we must issue a word of warning. It must not be supposed that because we thus increase the polar strength of the solenoid, we have even in the slightest degree augmented the electro-magnetic force itself. With a given current and a given length of wire, that force is a constant quantity, the sum total of which cannot, in any sense of the word, be increased by the addition of a mass of iron, or even by any variation in the disposition of the wire, whether we wind it into a spiral, a solenoid, or use any other device. Were we able to augment the total force by any of these means, there would be an end to the law of the conservation of energy, which, as has already been pointed out, declares that when any one force is produced or developed it can only be at the expense of an equal amount of energy previously existing in another or a similar form. Force is indestructible; neither can we create it. The doctrine, therefore, so frequently laid down that the introduction of an iron core increases the electro-magnetic strength of a coil of wire, is misleading. The only means of increasing that strength or force is by increasing the current, or, what amounts to the same thing, by increasing the length of wire and increasing the battery power in sufficient proportion to maintain the same current strength. Let us state positively, even at the expense of a little reiteration, that what we really do, by the introduction of the iron core, is to concentrate a much larger proportion of the available force at those points where it acts at the greatest advantage, namely, at the poles of the solenoid. We would impress upon the student the necessity for ever keeping these facts clearly in mind.

The amount of attraction or repulsion exhibited by the solenoids furnished with their iron cores might be used as a means of measuring current strength, but the arrangement is not a convenient one, owing chiefly to the difficulty in obtaining perfect freedom of motion, the liability of variation in the current strength, and the varying properties of the iron.

Were it not for these disadvantages we could keep the electro-agnetic force of one of the solenoids constant, and send the rrents to be compared and measured through the other. But ere Nature comes in to aid us, for it is found that if a piece of *ard* iron or steel is used as a core for the solenoid, it retains ore or less permanently a large portion of the electro magnetic operties originally produced by the current. The power or bility of retaining such effects or properties is known as the 'retentivity' of the iron or steel, and depends entirely upon its hemical composition and mechanical or molecular structure. This retentivity is the same property as that hitherto known as 'coercive force,' which was certainly a misnomer and a libel upon e metal. If retentivity corresponds to anything at all, it is to *ertia* rather than to anything that can fairly be described as oercive. The similarity to mechanical inertia is seen in the fact at those samples which transmit the lines of force freely, retain carcely any of the influences producible by them, while, on the ther hand, hard iron and steel, which resist the propagation of e lines of force, resist equally well the vanishing of these es after the cessation of the current which called them into xistence.

A piece of iron or steel which acquires and so retains the ower of acting as a solenoid, is called a permanent magnet, or mply a magnet, and its extremities are also called poles. The es of force still enter and leave the steel as they did before it

Fig. 40.

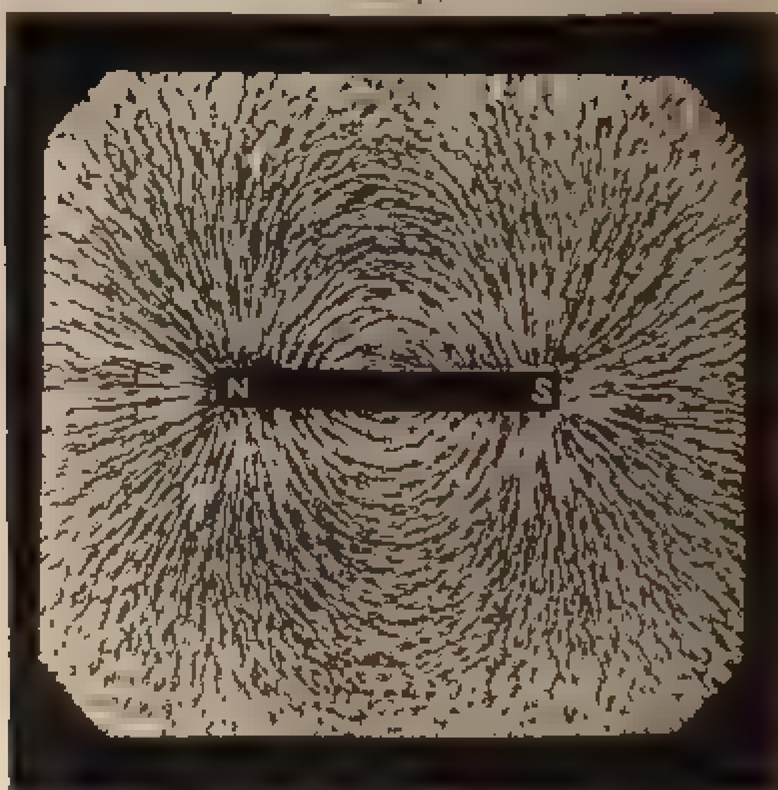


as removed from the helix, the direction being shown in fig. 40. he end, S, at which they enter is called the south-seeking pole of e magnet, and the other its north-seeking pole.

The actual arrangement imparted to iron filings sprinkled on a

sheet of paper placed over a permanent steel magnet is beautifully illustrated in fig. 41. Such a distribution of the filings would take place in any plane parallel to the axis of the magnet, for the lines of force radiate from the poles similarly in all directions. The

Fig. 41.



distribution observed when the paper is placed on the end of the magnet and at right angles to its axis is shown in fig. 42.

If we know the direction in which the current passes round a piece of iron or steel, it is easy to predict the direction of its polarity; for if we look at the end of the bar and the current is then flowing round it in a right-handed direction, as in fig. 43, that end will be a south-seeking pole; but if the current flow in a left-handed direction, as in fig. 44, that end will be a north-seeking pole.

It is the practice to enter into a detailed description of the difference between right- and left-handed helices with a view to facilitating a recollection of the electro-magnetic polarity. Thus a left-handed helix (fig. 45) is one in which, from whichever end the current enters, it will travel in the opposite direction to that

o by the hands of a clock, and will develop north-seeking ity at the end at which it enters and south-seeking polarity

FIG. 42.

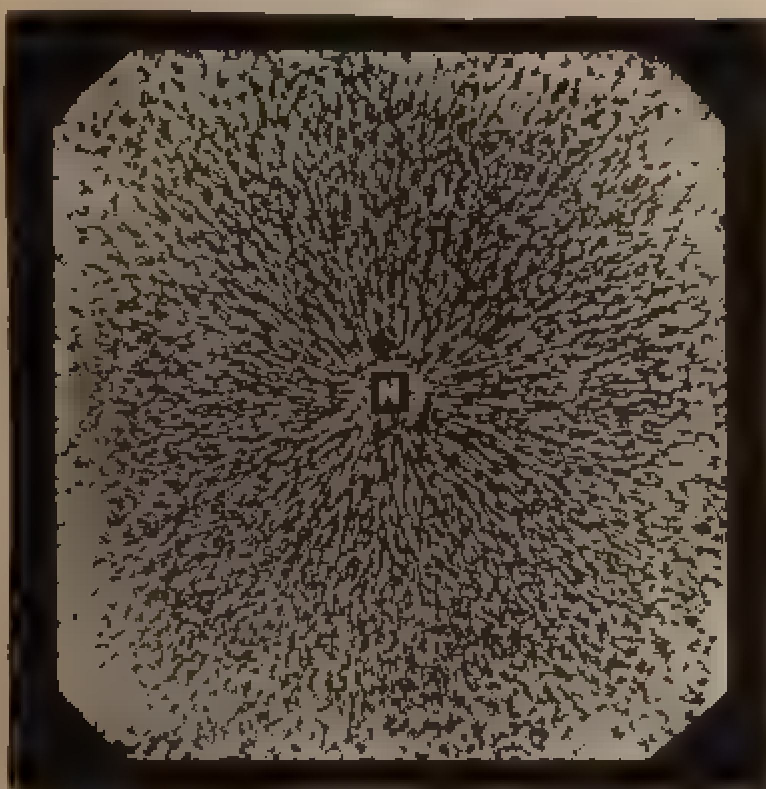


FIG. 43.

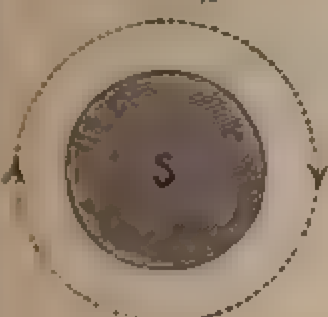


FIG. 44.

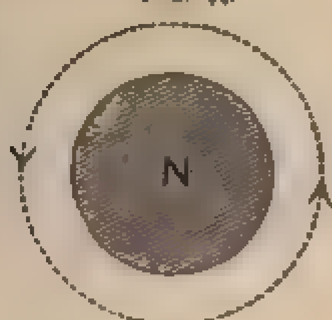


FIG. 45.

end of emergence. Conversely, a right-handed helix (fig. s one in which the current will travel round in the same ion as the clock-hands. In this, the entering end becomes

a south pole and the other a north pole. But all this is superfluous. It is sufficient to regard the cause and effect in the way indicated in the preceding paragraph.

FIG. 46.

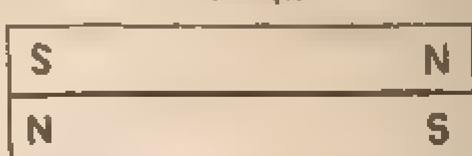
It is noteworthy that two magnets act one upon the other in precisely the same manner as two helices or a helix and a magnet, for in every case the movement or motion imparted is such as will tend to make the lines of force coincide. Thus, if one magnet, A (fig. 47), is brought near another, B, which is suspended

FIG. 47.

by a thread or pivoted on a needle-point at C, so that it can turn freely about its centre, the force exerted between them will endeavour to make the suspended needle take up such a position as to allow the lines of force due to both magnets to pass through them in the same direction. This will happen when the magnets are in line and when their opposite poles are adjacent, as shown in fig. 47. In other words, there will be repulsion between similar magnetic poles and attraction between dissimilar ones.

If, however, both magnets are allowed perfect freedom of motion, their ultimate position will be that shown in fig. 48, the

FIG. 48.



magnets then lying side by side with their dissimilar poles adjacent. In this position the coincidence of the lines of force is at a maximum, that is, the lines due to each magnet turn round at the ends and pass through the other, and in so doing assume the easiest path for their completion. If pieces of soft iron, called armatures

keepers were [illegible] ... of the lines of force [illegible] ... ch an extent that few [illegible] ... hese [illegible] ... ing for the small [illegible] ... is point we will [illegible]

The strength of a magnet [illegible] ... e force with which [illegible] ... ing equal to the product [illegible] ... presents the strength [illegible] ... her, similarly magnetised [illegible] ... x m. This [illegible] ... istances, but [illegible] ... at we might express [illegible] ... e simple formula

$$f = \frac{m \times m'}{d^2}$$

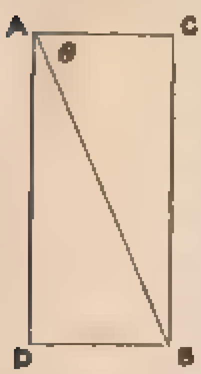
where d equals the distance [illegible] ... s important to bear in mind that the [illegible] ... poles of each magnet should [illegible] ... words, that the magnet should [illegible] ... the error that would be produced [illegible] ... the remote poles to an [illegible]

We have already defined the [illegible] ... magnet pole of unit strength [illegible] ... tance of one centimetre from a similar [illegible] ... it with a force of one dyne. [illegible] ... point in any field can be determined [illegible] ... repulsion at that point of a magnet pole [illegible] ... every case, then, the force acting upon a [illegible] ... multiplying the strength of the pole by the [illegible] ... the field in which it is placed. [illegible] ... of magnetic fields by the relative [illegible] ... is assumed that a field of unit strength [illegible] ... per square centimetre.

The earth itself is practically a huge [illegible] ... magnet, and behaves as such [illegible]

relatively near, but actually at some distance from, the geographical poles. If a magnet needle were suspended so that it could turn freely in a *vertical* plane, it would, with a plane of rotation east and west, point vertically downwards with its north pole; but if the plane of rotation were north and south, the needle would, in London, come to rest with the north-seeking pole dipping downwards, and making an angle—known as the angle of inclination or dip—of about 67½° with the horizon. If another magnet were suspended or balanced on a pivot in a horizontal plane, the needle would set itself approximately north and south, the north-seeking pole pointing to the north magnetic pole of the earth. The axis of the magnet—that is, the straight line joining its two poles—would actually make an angle—known as the angle of declination—of about 18°, with the geographical meridian passing through its centre. It will be observed that there is here a case of attraction between the north pole of the earth and the north seeking pole of the magnet; but this is no contradiction of the law that similar poles repel and dissimilar attract, inasmuch as the magnetic properties of the north pole of the earth are in all respects the same as those of the south seeking pole of a magnet. The earth's total magnetic force can be resolved into two components at right angles to each other, one acting in a vertical direction, tending to depress the north-seeking pole of the needle, the other acting in a horizontal direction and striving to make it point north and south. Their relative values may be found by the familiar parallelogram of forces (see fig. 49). The line A B is drawn making an angle θ with the horizontal equal to the angle of inclination, and the right-angled parallelogram which has A B for a diagonal completed with its sides horizontal and vertical. Then, if A B represents in length the magnitude of the total magnetic force, A C and A D will be proportional to the horizontal and vertical components respectively.

FIG. 49.

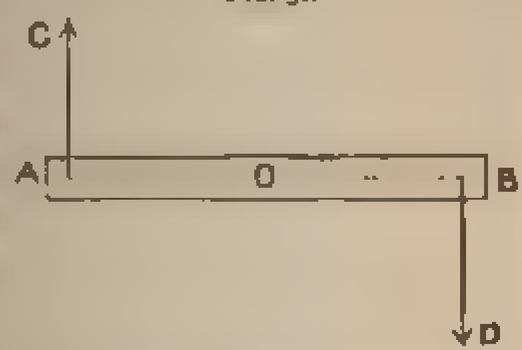


When the magnet is so balanced that it can only move in a horizontal plane, then a large proportion of the force—viz. the vertical component—is simply exerted in pressing the magnet on its support. The remainder, or the horizontal component only, is

effective in making the magnet point towards the magnetic north and south. On the other hand, when the plane of a dipping needle is at right angles to the magnetic meridian, or to the direction of the earth's lines of force, the vertical component only is active, and the magnet points vertically downwards, the horizontal component spending its force in pressing the pivots against their bearings, vainly striving to urge the needle round into the direction of the dip. A horizontally balanced magnetic needle is useful in pointing out the direction of these north and south magnetic poles of the earth.

In consequence of the immensity of the earth as a magnet, its magnetic field is practically uniform over any small space—that is, its lines of force are *parallel* and *equidistant.* It follows, therefore, that the poles of a needle floating on water are attracted or repelled with equal force in any position, and, as a consequence of this, the needle does not move bodily towards the north pole of the earth, but is simply directed so as to point north and south. It may be stated that it is a well-known law in mechanics that when two equal forces, parallel but opposite in direction, act at the ends of a rigid bar, they tend to turn it round its centre. The turning effect is greatest when the forces act at right angles to the bar, as do C and D in fig. 50, A B being the rigid bar. The amount of this turning effect M is equal to the sum of each of the two forces multiplied by its distance from the centre—that is,

FIG. 50.



$$M = (C \times OA) + (D \times OB),$$

whence, C being equal to D,

$$M = C(OA + OB) \quad \text{that is, } M = C \times AB,$$

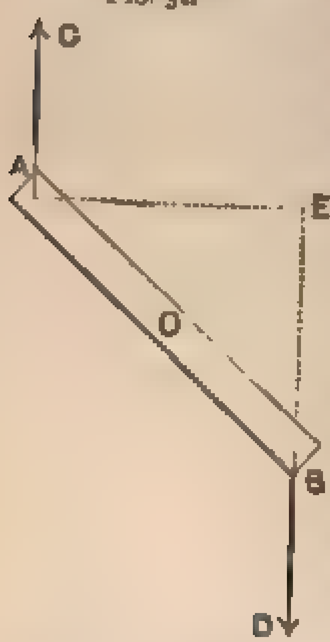
or the product of one of the equal forces into the perpendicular distance between them.

Such a pair of equal forces is called a couple, the perpendicular distance between their direction being called the arm of the couple, and the turning effect, M, as measured by the product

of one of the forces into the arm, is the moment of the couple. As the bar turns round or rotates, the moment M is decreased, the forces being the same but acting at less advantage in other words, the *leverage* is reduced. This will be more evident from a consideration of fig. 51, where the moment of the couple is $C \times A E$, the new perpendicular between the forces.

Reverting once more to the experiment with the floating needle, if we call the strength of one of the poles of the needle m, and let H represent the horizontal component of the earth's magnetic field, then the force acting on each end of the needle is $m \times H$. If we place the needle so as to point east and west, the arm of the couple is equal to the full length l of the needle, whence the moment is $m \times H \times l$. This moment decreases as the needle moves round towards zero, or that position in which it is pointing north and south. The moment is then reduced to nothing, M becoming $m \times H \times 0$, because the length of the arm is nothing; consequently, the needle remains at rest.

FIG. 51.

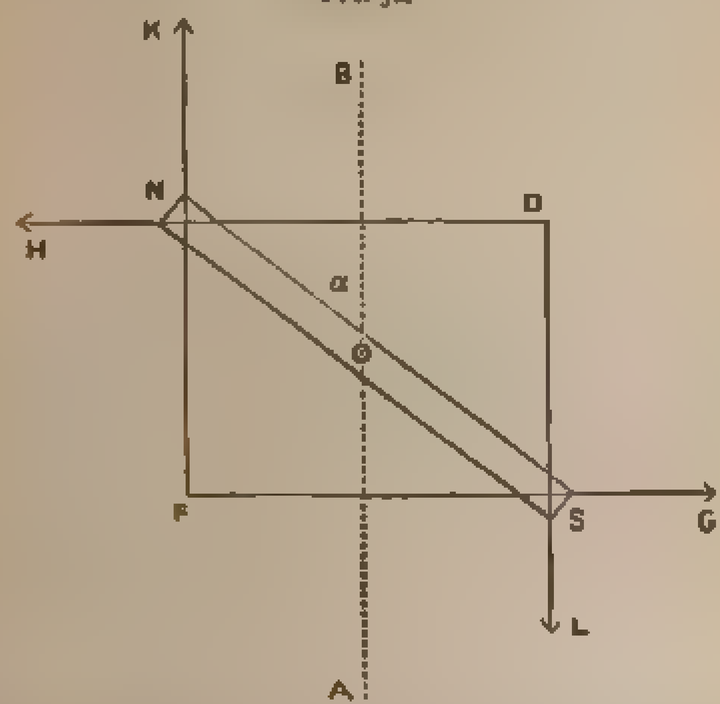


Now, we can cause any current, the strength of which we may desire to measure, to develop a field of strength f, at right angles to the earth's directive force—that is to say, we can cause the current to travel north and south, and by so doing deflect a magnetic needle from its zero position. Then the new force acting on each end of the needle will be $m \times f$, where m is the strength of the magnet pole; and, the length of the arm being calculated as before, the moment will be $m \times f$ multiplied by that arm. Manifestly, the needle will come to rest when the moment of the couple due to the current is equal to that due to the earth.

Let the needle N S (fig. 52) be so deflected by a current, and make an angle, N O B, called the angle of deflection, with the ...gnetic meridian A B. This angle N O B is, of course, equal to ...ngle N S D Let this angle be called $a°$, and let f be the ...gth of the field due to the current, the direction of the action

of which is indicated by the arrows D H and F G. D S is then the perpendicular distance between these directions, whence the moment of the couple due to the current is $m \times f \times$ D S.

FIG. 52.



By similar reasoning it will be seen that the moment of the couple due to the earth is $m \times$ H $\times$ N D. Now, if the needle has assumed a state of rest, showing that the moments of these two couples are equal, it follows, as a matter of course, that

$$m \times f \times \text{D S} = m \times \text{H} \times \text{N D},$$

and (by cancelling and dividing)

$$f = \text{H} \frac{\text{N D}}{\text{D S}}.$$

The ratio $\frac{\text{N D}}{\text{D S}}$ is called the tangent of the angle N S D, which, again, is equal to the angle of deflection $a°$ that is to say,

$$f = \text{H} \tan a°.$$

This strength of field, f, is proportional to the current producing it; therefore the current, C_1, is likewise proportional to H tan $a°$.

And this will be true of all currents and all deflections, so that if we let a second current, C_2, cause the needle to be deflected through the angle $b°$, then C_2 must be proportional to H tan $b°$.

Consequently, $C_1 : C_2 :: H \tan a^\circ : H \tan b^\circ$,

that is, $C_1 : C_2 :: \tan a^\circ : \tan b^\circ$,

or the two currents are directly proportional to the tangents of the angles through which they deflect the needle. By referring to a table such as is here given, we can find the numerical value of the

TABLE OF NATURAL SINES AND TANGENTS.

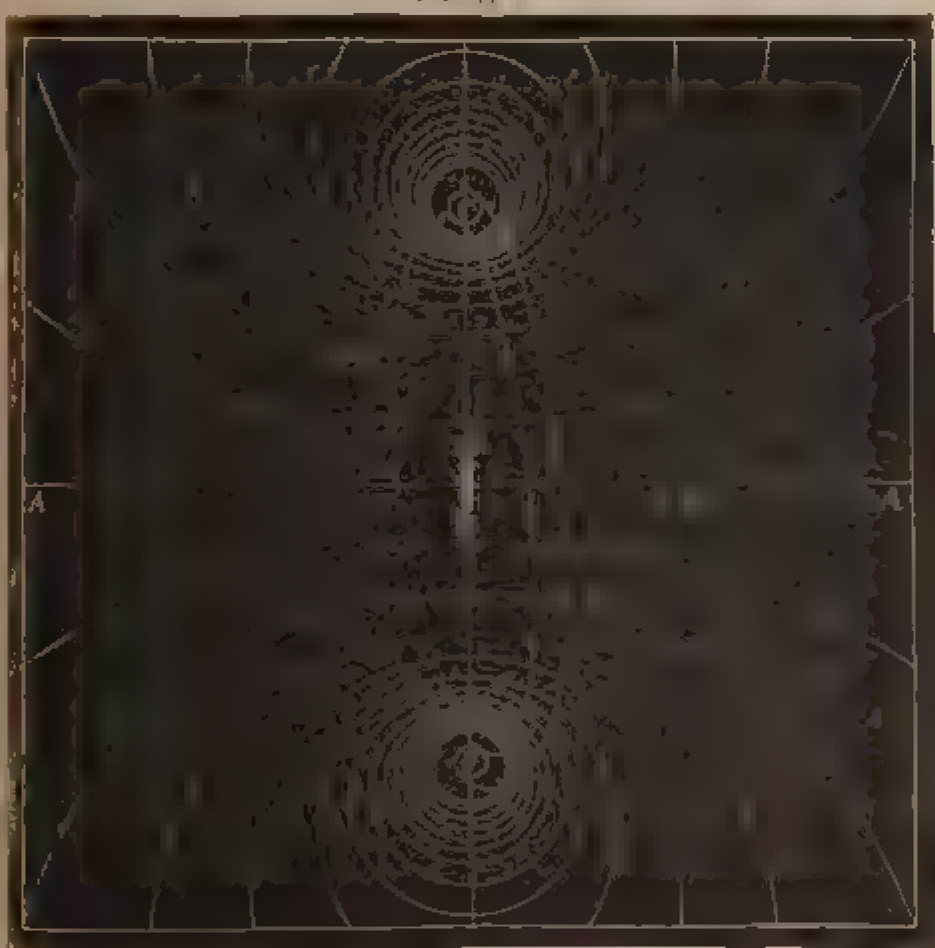
Deg.	Sine	Tangent	Deg.	Sine	Tangent	Deg.	Sine	Tangent
1	·017	·017	31	·515	·601	61	·874	1·80
2	·035	·035	32	·530	·625	62	·883	1·88
3	·052	·052	33	·544	·649	63	·891	1·96
4	·070	·070	34	·559	·674	64	·899	2·05
5	·087	·087	35	·573	·700	65	·906	2·14
6	·104	·105	36	·588	·726	66	·913	2·24
7	·122	·123	37	·602	·753	67	·920	2·35
8	·139	·140	38	·615	·781	68	·927	2·47
9	·156	·158	39	·629	·810	69	·933	2·60
10	·173	·176	40	·643	·839	70	·939	2·75
11	·191	·194	41	·656	·869	71	·945	2·90
12	·208	·212	42	·669	·900	72	·951	3·08
13	·225	·231	43	·682	·933	73	·956	3·27
14	·242	·249	44	·694	·965	74	·961	3·49
15	·259	·268	45	·707	1·000	75	·966	3·73
16	·275	·287	46	·719	1·03	76	·970	4·01
17	·292	·306	47	·731	1·07	77	·974	4·33
18	·309	·325	48	·743	1·11	78	·978	4·70
19	·325	·344	49	·755	1·15	79	·981	5·14
20	·342	·364	50	·766	1·19	80	·985	5·67
21	·358	·384	51	·777	1·23	81	·987	6·31
22	·374	·404	52	·788	1·28	82	·990	7·11
23	·391	·424	53	·798	1·33	83	·993	8·14
24	·407	·445	54	·809	1·37	84	·994	9·51
25	·422	·466	55	·819	1·43	85	·996	11·43
26	·438	·488	56	·829	1·48	86	·997	14·30
27	·454	·509	57	·838	1·54	87	·998	19·08
28	·469	·532	58	·848	1·60	88	·999	28·63
29	·485	·554	59	·857	1·66	89	·999	57·29
30	·500	·577	60	·866	1·73	90	1·000	Infinite

tangents of these or other angles, and so can easily compare the strength of the currents.

An instrument which will enable us to make these comparisons is called a tangent galvanometer; but in order to obtain accurate results one important point must be carefully attended to in designing the instrument, for the foregoing proof only holds good when the two forces forming a pair act parallel to each other in

and every position of the needle. This means, in short, that field due to the earth, and that due to the current, must be iform throughout the entire space in which the needle can be oved Fortunately, we can, by using a very short needle, make s space proportionally small, and thereby render the problem sier. The earth's field, as has been already stated, is uniform, t that due to a current is far from uniform, more particularly

Fig. 53.



the immediate vicinity of the wire, consequent on the very cided curvature of the lines of force. However, as we get ther away from the wire, these lines approximate more and e to straight lines, and if we bend the wire into a ring of large ameter we shall find a small space at its centre where the lines force are, to all intents and purposes, straight and parallel. In . 53 is shown a horizontal view of the ring and of the distribu- of the lines of force in the field. The two elapses repre-

purpose of obtaining a sensible deflection with comparatively weak currents. But this difficulty can be easily overcome, for we can increase the length of the wire, without increasing the distance from the needle, by the simple device of coiling it round the needle a number of times. Since the effect on the needle varies directly as the length of a wire, and the length of a wire of two turns is double that of one turn, the effect on the needle is doubled also; in other words, the effect on the needle varies directly as the number of turns of wire in the coil. It follows that, with equal currents, a 6-inch coil of one turn will give the same deflection as a 12 inch coil of two turns.

It must be remembered, however, that if the number of convolutions is increased to any great extent the resistance becomes considerable, and the very act of inserting the galvanometer in a circuit may decrease the current we desire to measure.

Bearing all these points in mind, we will now consider a really practical instrument for the measurement of current strength, selecting for description the pattern which is undoubtedly the best yet constructed—viz. the Post-Office tangent galvanometer. A general view of the instrument is shown in fig. 54.

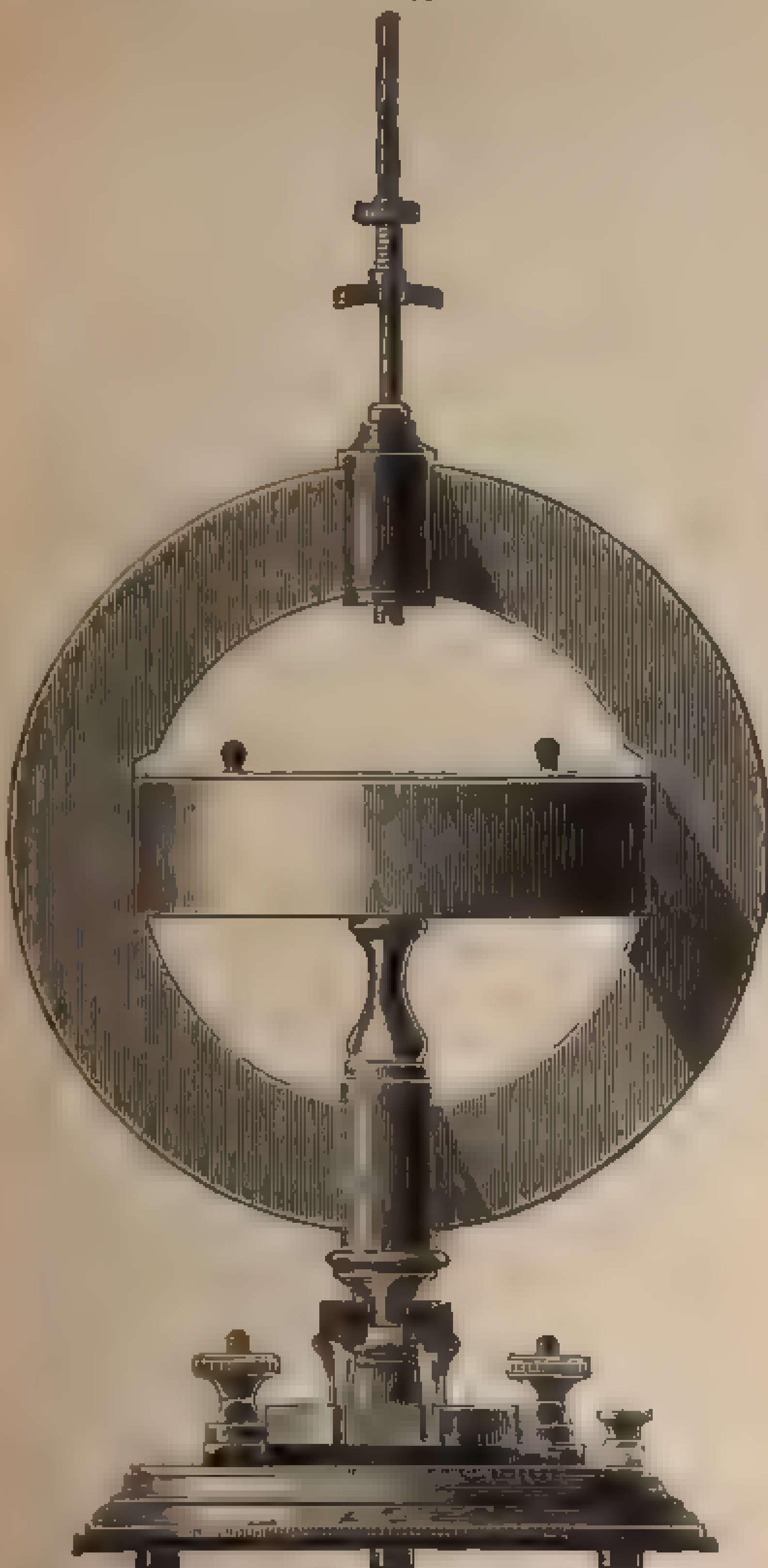
The casing is of brass. The mean diameter of the coil is $6\frac{1}{2}$ inches; the width of the channel in the brass ring which contains the wire is $\frac{5}{16}$ inch, and its depth $\frac{7}{8}$ inch. The length of the needle, which is carefully pivoted with agate on an iridium point, is $\frac{3}{4}$ inch.

As this needle is too short to indicate its own deflections, it carries a light pointer of gilt copper wire, about 5 inches in length, fastened to it at right angles. This pointer moves over an engraved circular scale plate, one half of which is divided in degrees, the other half into divisions corresponding to the tangents of those degrees, as shown in fig. 55.

It may be of service to some if we refer here to the manner in which this tangent scale is constructed.

Let the quadrant O L (fig. 56), represent a portion of the circle along which the scale is to be marked, and let C O be the radius along which the index needle is to point when at rest and when no current is circulating through the coil of the instrument. Then draw the tangent line, O D, that is to say, a line at right angles to

FIG. 54.



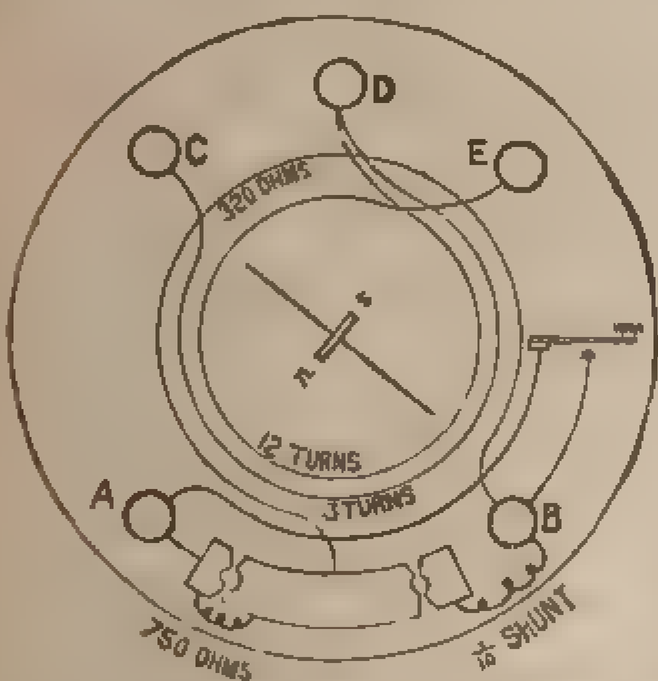
mparatively strong currents can affect the needle, and, as we
e seen, we are prohibited from reducing this diameter for the

reading the observer may let the pointer cover its own reflection, when he will be assured that he is looking vertically down upon it, avoiding thereby any error due to parallax—that is to say, any inaccuracy in reading caused by looking at the pointer sideways. A lever, operated by a small switch extending through the box which carries the needle and scales, is provided for lifting the needle off its pivot when not in use. There is also a small adjustable magnet which slides on a brass rod over the needle, and is used for varying the sensibility of the instrument. This may appear to be a step backwards from the beautifully simple thesis upon which the instrument is constructed. If there were no good reason for introducing this 'controlling' magnet to vary the sensibility of the instrument, the wisdom of its introduction would be questionable. But it must be remembered that there are several hundreds of these instruments in use throughout the country, and if it is known that a reading of twenty-five divisions corresponds in every case to a current of 1 milliampere, the direct value of any other reading can be confidently estimated. The controlling magnet, when placed with its S. pole over the N. pole of the needle, assists the directive force of the earth's magnetism and reduces the sensibility, and *vice versâ*. Either effect may be varied by sliding the magnet up or down the rod. For instance, the needle will move from zero with the weakest current when the magnet is placed at the bottom of the rod with its poles opposing the earth's magnetism.

A reference to fig. 57 will make the conception of the electrical portion of the instrument easier. There are three separate coils of wire in the brass ring, or bobbin, the ends of each being brought down through the hollow pillar and connected under the base of the instrument to their respective terminal screws, as shown in plan on the figure. Between the terminals C and D is a coil consisting of three turns of thick wire; between D and E are twelve turns of similar wire, wound in the oppos[ite] direction. If the current be sent from C to E, we get nine tu[rns] acting on the needle, for three of the twelve turns are neutrali[sed] by the three in the opposite direction between C and D. T[he] [re]sistance of these coils is negligibly low, so that we are a[ble to] get the effect from three, nine, or twelve turns without vary[ing]

..ength of the current. The other coil consists of a great .. turns of fine silk covered wire. Its resistance is exactly ..hms. One end of it is joined to terminal B, and the other ..o the middle brass block. By inserting a brass plug in the

FIG. 57.



..nd hole, the end of the coil attached to the middle block is ..ected to terminal A direct. If, however, this plug is removed, ..urrent in travelling, say, from B, has to pass through an ..ional resistance coil of 750 ohms (which is fixed under the .. of the instrument) before it reaches terminal A. Under these ..nstances the total resistance between A and B is 1,070 ohms. ..ose now a single Daniell cell, whose resistance is compara.. low, to be joined to terminals A and B. By Ohm's law the ..nt is equal to $\frac{1\cdot07 \text{ volts}}{1{,}070 \text{ ohms}}$, or ·001 ampere—that is, 1 milli..re.

..hese resistances are, in fact, calculated for use with a single ..ell cell as a standard. We can always immediately produce ..flection which we know to be that due to 1 milliampere ..rrent, and find the value of any other current by observing ..flection under similar conditions. A small key is fixed on ..se of the instrument; when depressed it connects A and B

as will be seen from fig. 57, or, in the usual language, it short-circuits the coils. It is used for checking the oscillations of the needle and bringing it quickly to rest.

It is sometimes required to measure a current so strong that the deflection is inconveniently high. In this case a part of the current may be 'shunted,' or provided with an alternative path, or, more correctly speaking, a by path, so that only a portion of the current shall go through the galvanometer, the rest going through the shunt. It is necessary, however, to know exactly what fraction of the total current is passing through the instrument and what through the shunt. If we join the ends of the coil by a shunt equal to it in resistance, then the current will divide equally between the two paths, and only half of the total current will be measured. If the resistance of the shunt be $\frac{1}{9}$ that of the galvanometer, then $\frac{9}{10}$ of the current will pass through the shunt and the other tenth through the galvanometer. In this case, therefore, the total current will be ten times that measured by the deflection of the needle.

The instrument we are now describing is provided with such a shunt; its resistance is $\frac{280}{9}$ ohms, and fig. 57 clearly shows how it may be brought into play by inserting a plug in the right-hand hole, thus connecting together the middle and right-hand blocks. Suppose, when the adjustment is such that 1 milliampere gives twenty seven tangent divisions, that we insert this tenth shunt, and then with a current of unknown strength obtain eighty one divisions. The current flowing round the galvanometer is manifestly 3 milliamperes, but this is only $\frac{1}{10}$ of the whole, consequently the total current is 30 milliamperes.

In order to reduce the current flowing through a galvanometer to any fraction of its full value, say, to $\frac{1}{n}$, the resistance of the shunt necessary to produce that result must be $\frac{1}{n-1}$ that of the galvanometer. A moment's reflection, however, will make it evident that the introduction of a shunt reduces the resistance of the circuit, d may, therefore, cause a considerable and material increase in current strength. Where this increase of strength is appre-le, the introduction of extra resistance sufficient to compensate

for the fall caused by the shunting becomes necessary, the problem being to ascertain exactly how much compensating resistance is required. By the laws of the joint resistance of two parallel wires, explained in Chapter II, the joint resistance of the galvanometer, G, and the shunt, S, will be equal to $\frac{G\,S}{G + S}$. Now, the resistance of S has just been shown to be $\frac{1}{n-1}$ part of G, or $\frac{G}{n-1}$, that is, if only a tenth of the current is to pass through the galvanometer, the shunt resistance should be $\frac{1}{10-1}$ part of the galvanometer resistance G. That is to say, $S = \frac{G}{n-1}$, and inserting this value we get—

$$\frac{G\,S}{G + S} = \frac{G\,\frac{G}{n-1}}{G + \frac{G}{n-1}},$$

which is equal to $\frac{G}{n}$.

So that the joint resistance of a galvanometer coil of 320 ohms and its tenth shunt will be $\frac{G}{n} = \frac{320}{10} = 32$, whence it follows that the reduction in resistance due to the use of the shunt amounts to $G - \frac{G}{n}$, or $320 - 32 = 288$. 288 ohms is, therefore, in this case the resistance that it would become necessary to introduce in order to restore the resistance of the circuit to the same value that it had prior to the introduction of the shunt. And, generally, it may be said that the introduction of a shunt reduces the resistance of the circuit to the extent of $\frac{n-1}{n}$ G, and that amount of resistance will need to be inserted to re-establish the conditions of the circuit. In short, this compensating resistance is equal to the difference between the resistance of the galvanometer alone and of the galvanometer shunted.

When great accuracy is desired, all the readings on the tangent galvanometer should be taken with the needle deflected as nearly

as possible through an angle of 45°. The reason for this is, that any given variation in the strength of the current will produce a greater effect on the needle when it is in that position than when in any other, or, in other words, the sensitiveness of the instrument is then at its maximum. For instance, if, when the needle were deflected through 45°, an increase of the current by one-twentieth gave an increase of half a degree in the deflection, a similar increase in the current when the needle stood at 10° or 80° would not be indicated at all, or rather, the deviation would not be discernible.

Every galvanometer has a definite *angle of maximum sensitiveness*, or such an angle of deflection that with a small accretion of current there will be a larger divergence than when the needle is at any other point on the scale. The mathematical demonstration of the existence of this angle would be somewhat beside the scope of this work, but we may repeat that for every tangent galvanometer the angle of maximum sensitiveness is 45°. We should always endeavour, therefore, when using this instrument to get the deflection as near 45° as possible, or when comparing two currents get the deflections at equal distances on either side of this point. It has already been pointed out that it is very convenient, we would say more, it is necessary, in practice to be able to determine immediately the value in amperes or milliamperes, to which some particular deflection of the needle corresponds, and it will be remembered that with a Daniell cell as a standard a current of 1 milliampere may be immediately produced.

The Latimer-Clark cell is less liable to variation and is much more trustworthy than the Daniell when used with a very high external resistance. Although, in order to obtain the most accurate results, this cell should only be employed in those tests where it is not allowed to send any current at all, its portability and the fact that it is always ready and in good order are such important advantages that it is frequently used in such a test as the preceding, under conditions which, perhaps, render it no more accurate than the Daniell. Its resistance, which is as a rule considerable, should be known, and, by using an extra coil, the resistance in circuit can then be made 1,435 ohms. The electromotive force of one of these cells being 1·435 volt, it follows

that through the resistance of 1,435 ohms it will yield a current of exactly 1 milliampere, or,

$$\frac{1{\cdot}435}{1{,}435} = {\cdot}001 \text{ ampere.}$$

The foregoing applies to a galvanometer with a tangent scale constructed so that its zero point is in the centre, as is the case with the *inner* scale on the tangent divisions side in fig. 55. But it will be seen that in this figure there is an outer scale also of tangent divisions, but with the zero point at the extreme left-hand, where the pointer is shown resting. This outer scale is known as the 'skew scale,' from the position of the needle when at zero, and its great advantage lies in the fact that the range of measurement is double that of the ordinary scale. For a comparatively high reading, also, the deflection can be read with greater ease as the pointer is not in the part of the scale where the divisions are close together. It is true that a small deflection cannot easily be read, but the ordinary scale can be employed for this if necessary.

Unfortunately, the tangent galvanometer is but little suited for the measurement of very powerful currents such as those generally employed in electric lighting. We must, therefore, now direct attention to an instrument which will answer this purpose, and one which is beautifully simple in its conception, and at the same time remarkably accurate and free from error. It is based upon the simple experiment mentioned at the commencement of this chapter, viz., the attraction or repulsion which takes place between two wires carrying currents. It may now be stated that the force of this attraction or repulsion is readily measurable, being, in fact, proportional to the strength of one current multiplied by the strength of the other, provided that the distance between the two wires remains constant. If we suppose the currents in each of the wires to be exactly equal, say 2 amperes, then the force may be represented by the number $2 \times 2 = 4$. Now if we double the current strength in each wire, the force of attraction or repulsion will be $4 \times 4 = 16$; in other words, when the current strength in each is doubled, the force between them is quadrupled. Similarly, if we treble the current in each wire, or make it 6 amperes, then the mutual force will be $6 \times 6 = 36$, or nine

ampere and the torsion applied 16 divisions. Then if a current of unknown strength be sent through the same coil, and it is necessary to apply 64 divisions of torsion to bring the rectangle back to zero, the latter current will be 2 amperes strength; for

$$c_1 : c_2 :: \sqrt{16} : \sqrt{64},$$

that is as 4 is to 8, or as 1 is to 2.

In practice such calculations would be exceedingly inconvenient; the makers, therefore, calibrate the instrument, or determine what strength of current corresponds to the various angles of torsion, both for the thin- and thick-wire coils. These results are tabulated in a convenient form and supplied with the instrument.

On referring to fig. 59 it will be observed that, if the current is reversed, the rectangle will still be deflected in the same direction, because, the direction of the current in *all* the sections being altered, attraction or repulsion will take place between the same limbs as before.

The instrument can therefore be used to compare either positive or negative direct currents, or even alternating currents—*i.e.* those whose direction is rapidly reversed. The pointer attached to the screw-head should always stand at zero when the instrument is not in use, otherwise the spiral spring will take up a *set* and will not bring the rectangle to zero when the pointer is brought there. The spring will, however, gradually recover from any such set if it be not excessive.

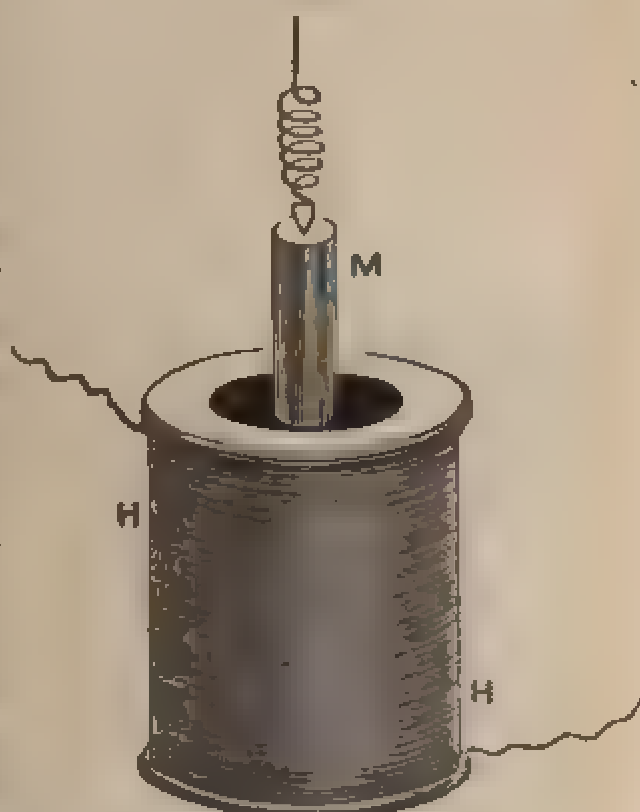
The Siemens dynamometer is a very accurate instrument when used with ordinary care, but every measurement occupies a certain amount of time, for in every case the rectangle has to be brought back exactly to zero, the amount of torsion noted, and then the table referred to, to ascertain the current strength to which the torsion corresponds. It is evident that an instrument which immediately indicates in amperes the strength of the current flowing is far more convenient to use, although, unfortunately a *direct-reading* instrument has not yet been designed which may be relied upon for any length of time to be as accurate as the Siemens dynamometer.

For portability and the rapidity with which measurements may

o, Ayrton and Perry's ammeter (or ampere-meter) stands font rank.

s based upon the fact, that a piece of soft iron placed in etic field which is not uniform, will be urged from a comely weak into the strongest part of the field. One way of g the action is to consider the iron, M (fig. 60), as a magnet e time being, and the field be geneby a current circulatand a helix of wire, d the iron is placed tside the helix, it e sucked down until hes the middle of elix, which is the est part of the field. this action will be tional to the proof the strength of the nd the strength of mporary magnet; as ter varies with the h of the field, but ording to any regu-, the readings will proportional to the strength unless by some means the strength of this temporary is kept constant. Experiment shows that although the ic lines of force pass readily through a piece of iron when e very few lines already there, yet, when a great many are any further addition to their number becomes very . When in this latter condition the iron is said to be ed.' A piece of *very thin* soft iron tubing becomes d even in a weak field, that is, in a field traversed by but s of force; so that beyond a certain stage, although the of the field is increased, the number of lines of force through the iron tubing, that is, its strength considered as t, remains practically the same. Therefore, if we use a

FIG. 60.



very thin tube of soft iron, the force with which it is sucked into the helix will, for all fields above a certain strength, depend simply upon the strength of the field and will be proportional thereto, and consequently, also proportional to the strength of the current producing the field.

Except for weak currents, then, we may estimate the strength of a current by measuring the pull on such a thin tube of iron placed partly inside a helix. It must not be placed exactly in the middle of the coil, as that, being the strongest part of the field, is the position of rest for the iron.

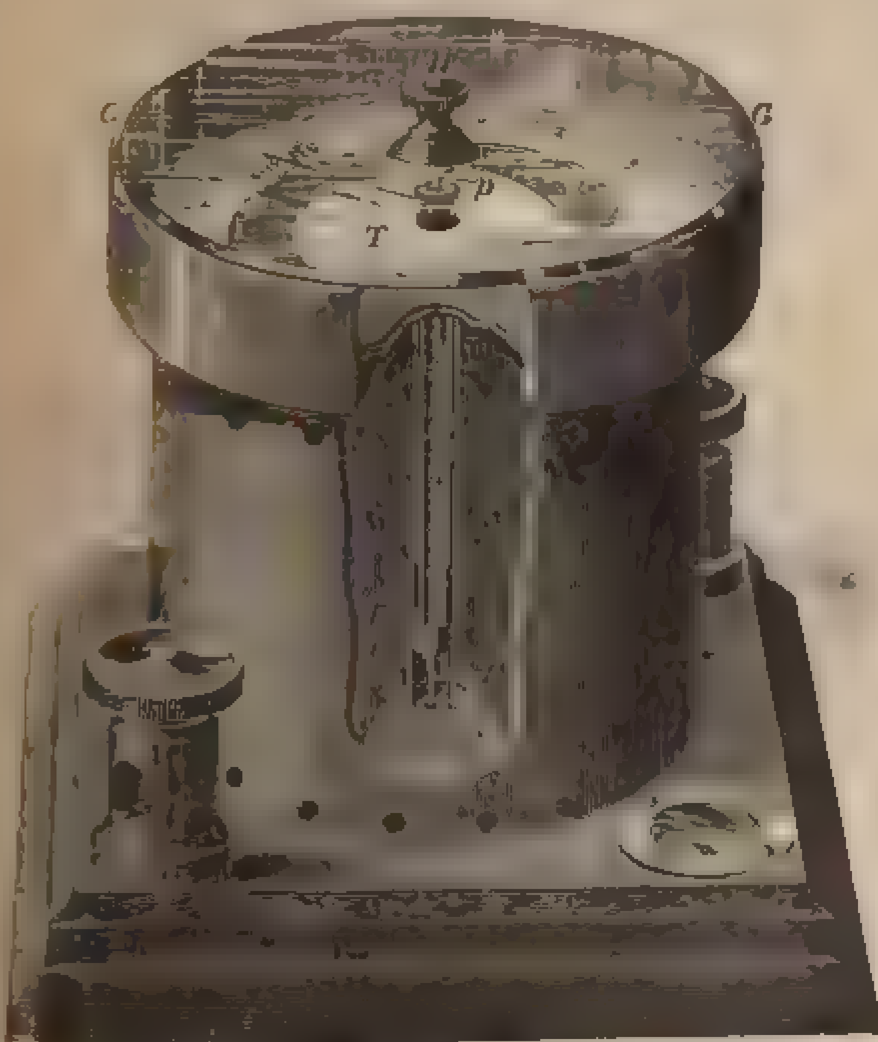
In the instrument under consideration the method of measuring the pull is unique. It depends upon a peculiar property possessed by a flat spiral spring shaped like a curled-up shaving, as illustrated in fig. 61. If such a spring be stretched while one end of it is fixed, the other end will rotate, and the angle of rotation will be exactly proportional to the amount of stretching, the angle being considerable for a small extension of the spring. A reference to fig. 62 will show how these principles are combined in the actual instrument.

FIG. 61.

The helix fills the space marked W W, and is composed of stout wire offering little resistance, so that its introduction into a circuit does not diminish the current flowing therein. T is the thin tube of soft iron which is sucked down more or less by the current, its lateral movement being prevented by two small brass pins, P and *p*. The former is fixed to a small piece of brass, C, which is fastened to the bottom of the soft iron tube. The spiral spring is placed inside this tube, its lower end being rigidly fixed to C and its upper end to the brass pin *p*. As *p* is also rigidly connected to the screw head, H, the upper end of the spring cannot rotate, therefore when the tube T is sucked down the lower end of the spring rotates, carrying with it the tube. The upper end of the tube which projects out of the coil carries a

pointer which moves over a graduated scale, and so indicates the angle of rotation, the usual horizontal mirror being provided to avoid parallax. The scale is divided into equal divisions representing amperes and fractions of an ampere, but as the iron does not become saturated until the current has attained a certain strength, the first portion of the scale is never used, and is, in fact, not graduated, for, as has been explained, the indications at this

Fig 61.



stage are not proportional to the current strength. It is clear that if the iron tube moved through any considerable distance so as to get into a part of the field of different strength, the readings would not be proportional; but it will be remembered that the peculiarity of the spring is that the angle of rotation is great for a very small extension in length, consequently the pointer traverses the whole

shall not affect the reading, the main leads are connected to two long pieces of wire which are twisted together for a considerable distance as shown in the figure, so that each neutralises the tendency of the other.

We come now to the consideration of a class of ammeter, simple in construction and action, independent to a great extent of the proximity of extraneous electro-magnetic fields, and, being direct-reading instruments, they are exceedingly useful as dynamo-room indicators, telling the attendant at a glance whether or no his current is being maintained at its proper value. A number of these instruments depend upon the power of a coil alone, to raise

FIG. 65.

FIG. 64.

a more or less weighty piece of iron against the force of gravity, while others have a solenoid and core to perform a similar operation. They all require to be calibrated, but, under the circumstances, that is not objectionable providing the calibration is correctly performed.

The first instrument of this class to which we will refer is that constructed by Schuckert. A general view of this ammeter is shown in fig. 64, and a view of the moving portion of it in 65. It will be seen that the instrument is made to be fixed

gainst a wall with its base in a vertical position, the working parts being protected by a circular metal case with a glass front. From the two terminal clamps below the instrument case, stout metal bands are led to the solenoid, which is placed with its axis horizontal, and consists of single copper casting, with helical saw-cuts, so as to lead the current a few times round the 'needle.' With such a solenoid, which is designed for very heavy currents, no insulating material is employed other than the air; but in the case of instruments constructed for the measurement of weaker currents, the solenoid is made of a number of turns of ordinary stout insulated wire. A light steel arbor or spindle is pivoted so as to lie parallel to, and a little to the left of, the axis of the coil. It has attached to it a thin curved plate of soft iron shaped as shown in fig. 65. This piece of iron is nearly equal in length to the arbor, and extends through the length of the solenoid. A light aluminium pointer is also fixed to the arbor at right angles, and the movable parts are so weighted that, in the absence of a current, the pointer is held in the zero position by the force of gravity.

When a piece of iron is placed in a solenoid, but out of centre, the effect of a current is to bring the iron towards the centre. Therefore a current passing through the coil of the Schuckert instrument, in endeavouring to rotate the curved piece into the centre, raises it against the force of gravity, through a distance depending upon the strength of the current. The index attached to the arbor travels, therefore, over the scale which is placed behind it, and thus indicates the strength of the current passing through the instrument. As may be imagined, the divisions of the scale are unequal, but the scales of all instruments of the same range are exactly alike, the centre of gravity of the moving parts in each case being adjusted to suit the scale. The adjustment is made by bending a small piece of copper wire (see fig. 65) fixed at one end to the upper side of the arbor, but this operation is a matter of some difficulty when it is desired to reproduce a previous calibration. It is an interesting fact that the gross weight of the moving part is but $\frac{1}{30}$ of an ounce. The amount of friction is therefore very slight, and, there being very little in the instrument which is liable to vary with ordinary workshop usage, it is a useful and practical piece of apparatus.

The instrument known as the 'Gravity' ammeter is the invention of Mr. S. Evershed; it is manufactured by Messrs. W. T. Goolden & Co., and is for practical work an excellent and reliable measuring instrument.

In this case also the magnetising coil is placed with its axis horizontal, and in the middle of it there lies a small cylindrical piece of soft iron, *a* (fig. 66), which is fixed, by means of a piece of brass, to a brass arbor, this arbor being pivoted at its extremities, and weighted so as to keep the small iron rod in the position shown. F and F are two small soft iron slabs, placed end to end, but just sufficiently far apart for the small iron rod, *a*, to swing freely between them.

FIG. 66.

The coil encircles these slabs, the arbor, and its attachments; and when a current passes through it, the lines of force gather up into the slabs, and pass lengthways along them, say from F to F, with the result that there is a very dense field just between their opposing ends.

In its normal position the small iron rod, *a*, lies almost outside this dense field, and we have seen that a piece of iron so situated is always urged from a weak part towards the strongest part of the field. Consequently, the iron piece, *a*, is drawn down against the restraining force of gravity which acts on the counterbalancing weight, and, as an increase in the current strength will add to the number of lines and to the force of attraction, the distance through which the iron piece is moved may be made to indicate the current strength. But the depression of the iron rod is not proportional to the increase in the current, consequently an ordinary degree scale, or any other equally divided scale, cannot be employed. Reverting for a moment to the construction of the instrument, it should be explained that, as shown in fig. 67, the two iron slabs (F, F, fig. 66) are fixed upon a stout brass strip, the remote end of which carries a brass disc forming one bearing for the arbor. At the near end of the strip is a larger disc, provided with a hole through which the spindle freely passes, having also

and thence round the coil again to the beginning of the third convolution, at the right of, and underneath, the drilled hole. After again going round the coil the current leaves by the bar B. It thus takes about $2\frac{1}{2}$ complete turns round the coil, which, with a current of 300 amperes, would give 750 ampere turns.

It will be evident that such a coil has very little resistance, and that therefore the power absorbed and the amount of heat developed in it will be correspondingly small. The instrument may consequently be kept continuously in circuit without any risk of damage or serious waste of energy. The bars by which connection is made are long and straight, to prevent the current in the leading wires affecting the 'needle,' for without these precautions a considerable error might, owing to the small number of convolutions, be introduced. In an instrument for measuring 1,000 amperes the 'coil' consists of a massive cylinder divided on one side by a radial saw cut, with the straight connecting bars placed in a line with each other. In this case the current makes but $\frac{3}{4}$ of a turn round the needle, thus again giving, with 1,000 amperes, 750 ampere turns.

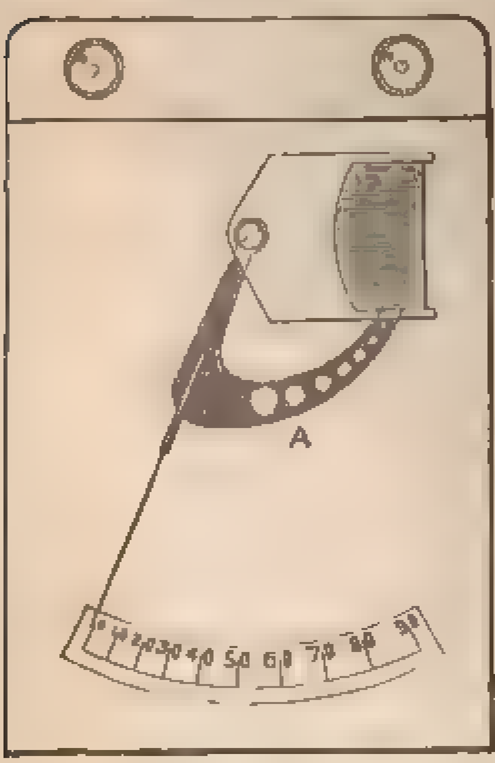
There is one possible source of error with instruments of this description due to the retentivity of the iron, but by exercising great care in the selection and treatment of the metal, this error has been practically eliminated. The iron, in fact, is not touched by a tool after it has been annealed, the film of oxide formed during that operation being simply dissolved by immersion in an acid. Perhaps the best way of testing for inaccuracy due to this cause is to take two sets of readings, one with ascending values of the current from zero to the maximum, and the other with corresponding descending values. Any retentivity of the iron would cause the latter set of readings to be higher than the former, but in these instruments the results are practically identical.

It is not so easy to accurately measure a current of several hundred amperes as it is to measure a few amperes or a fraction of an ampere, but all these ammeters are calibrated by having their full current passed through them, and its effect, as indicated by the pointer, carefully observed.

The required current strength is obtained by means of

secondary batteries, which are charged in series and joined up in parallel for discharging, and in order to ensure greater accuracy a definite fraction only of the whole current is measured. For example, if it is desired to calibrate an ammeter which is capable of measuring from 40 to 400 amperes, it is joined up with the secondary battery, and a set of 100 rather stout iron wire resistances, these wires being all joined up in parallel, and placed so as to have equal facilities for cooling. A standard ammeter is joined up in circuit with one of these iron wire resistances, and a length of the iron wire equal in resistance to that of the ammeter is removed, so that this compound branch, formed of a portion of iron wire and the ammeter, is equal in resistance to each of the other 99 branches consisting only of iron wire. This standard ammeter is calibrated with extreme care, and as the main current divides equally among the 100 branches, the ammeter accurately measures one-hundredth of it, so that for the maximum current of 400 amperes it is only necessary to measure 4 amperes—a comparatively easy matter. For 1,000 amperes it would thus be necessary to measure only 10; but an ammeter designed to measure such a high current is conveniently calibrated by joining in series with it two 500-ampere meters which are themselves connected together in parallel.

Fig. 69.



The absence of a portable instrument which will stand a little rough usage has hitherto restricted the measurement of alternating currents to such rather inconvenient instruments as the Siemens dynamometer, but it has recently been discovered that by slightly altering the proportions of the iron parts, these gravity ammeters answer admirably for measuring alternating currents, the difference in the readings caused by any variation in the rate of alternation within the limits

which obtain in electric lighting (that is, from about 50 to 120 alternations per second) being practically *nil*.

A simple form of gravity ammeter is that shown in fig. 69, and made by the Société des Téléphones de Zurich. The indicating needle is attached to a peculiarly shaped tongue of very thin soft sheet iron, A, which is furnished at intervals with a number of holes. These holes afford a means of adjusting the sensibility of the instrument and making the scale open near any desired reading. As the current passing through the coil increases in strength the tongue is drawn up into the bobbin and the needle made to pass over the scale on the face of the instrument.

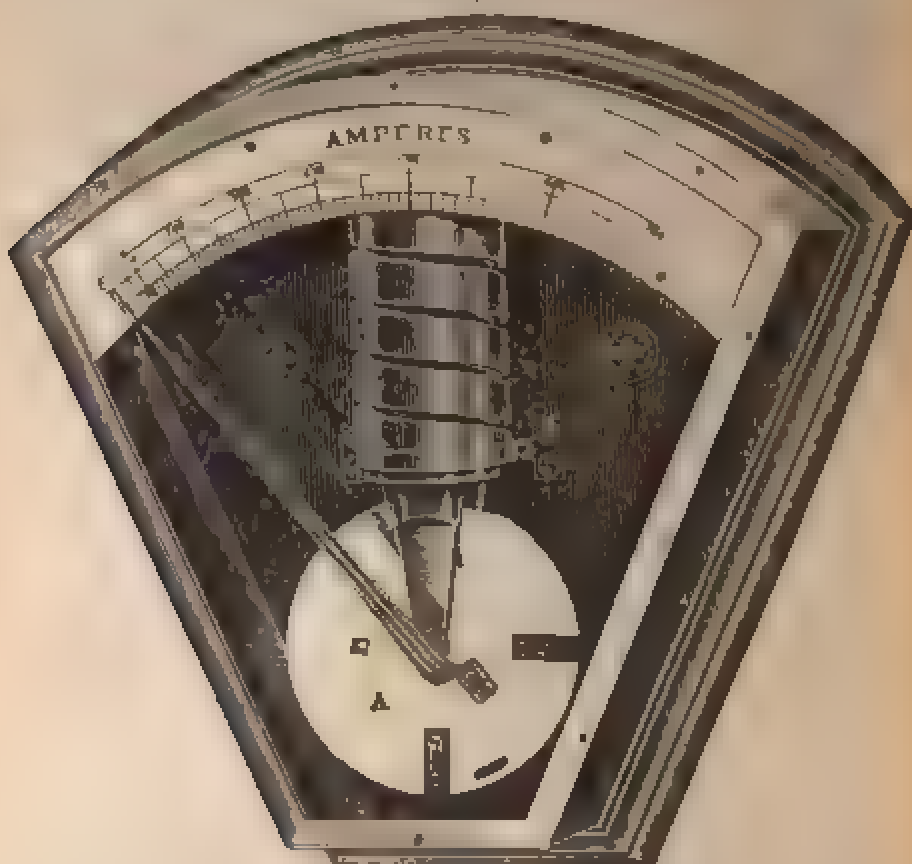
The 'Steel-yard' ammeter, made by the Electrical Power Storage Company and illustrated in fig. 70, is a useful and interesting piece of apparatus.

FIG. 70.

It consists of a coil of thick wire, which, for heavy currents, is simply a copper rod bent into a spiral and enclosing a soft iron core, which, on being magnetised, attracts a soft iron armature attached to one end of the steel-yard lever. A sliding weight is suspended from the other arm of the lever, its position being adjusted until it just balances the force of attraction between the core and its armature. This instrument is very convenient from the fact that its sensitiveness can be varied in several ways, such as varying the weights, &c. The range can also be varied by varying the length of the lever. The range of each instrument is considerable, the one illustrated being designed to indicate from 50 to 250 amperes.

The 'Disc' ammeter of Messrs. Drake and Gorham (fig. 71) is another useful and simple instrument. It consists of a spiral of copper ribbon enclosing a soft iron core, having for its armature a soft iron disc A. When the pointer stands at zero, as shown in the figure, the centre of gravity of the disc is just below the suspending pivots, which are carried by two pieces of brass attached to the core, the disc rotating between them. A small segment of the disc is cut off so as to form a slight prominence, which serves

FIG. 71.



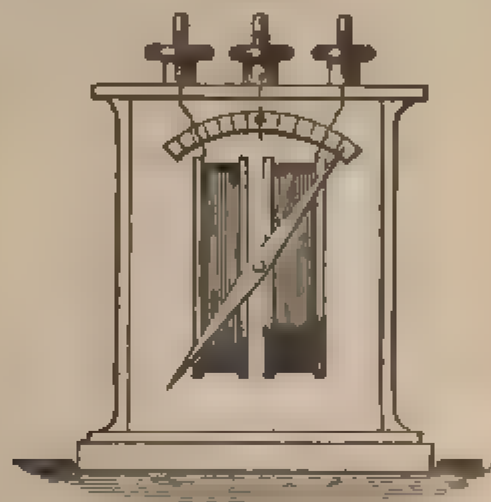
as a means of, to some extent, concentrating the magnetic lines of force at a definite point. As the strength of the current increases the attraction of this portion of the disc causes the heavier section to be raised against the force of gravity. A light non-magnetic index needle is fixed to the disc, and as the latter rotates the needle travels over a clear open scale.

The lineman's detector (figs. 72 and 73) is a very handy instrument when used for tracing circuits and localising faults, but it must not be regarded as a measuring instrument. It consists of

ordinary instrument bobbins, mounted vertically, and each ...d with two coils of wire, one consisting of a few turns of thick

FIG. 72.

FIG. 73.



... and the other of many turns of fine wire. The former is ...ally wound to 0·2 ohm, and the latter to about 100 ohms. A

FIG. 74.

FIG. 75.

...nt coil is sometimes added to the thick wire coil to reduce its ...itiveness. The magnet is about an inch long, and is mounted

on a horizontal axis (see fig. 74), so that it can turn freely inside the coils, a long non-magnetic indicating needle being also fixed on the front end of the spindle and moving over a graduated dial. Sometimes a soft iron needle is substituted for the magnetised steel one, it being magnetised by the induction of two powerful steel magnets fixed to the bobbins, one of which is shown at *m* in fig. 75. These magnets can be curved so as to fit into a case of ordinary dimensions.

One end of each of the coils is connected to one or other of the outer terminals on the top of the case, the other two ends being both joined to the centre terminal. Constructed as described, the needle should be deflected through 40° or 50° by a current flowing through the thin wire coil of 9·3 milliamperes—that is to say, by a single Daniell cell having an internal resistance of 7 ohms. The thick wire coil should, with the same cell giving a current of 139 milliamperes, cause a deflection of 20° to 30°.

CHAPTER V.

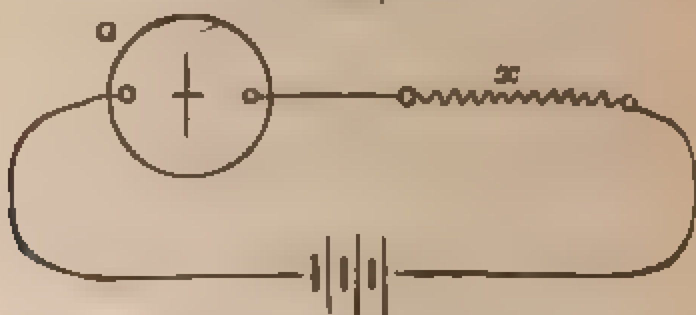
MEASUREMENT OF RESISTANCE.

WHEN the difference of potential in volts between the two ends of a wire is known, and also the current in amperes which that difference of potential is able to maintain in the wire, then the resistance of that wire in ohms may easily be calculated, for by Ohm's law it is equal to the number of volts divided by the number of amperes, or $R = \frac{E}{C}$, where E stands for the electro-motive force in volts, C for the current strength in amperes, and R for the resistance in ohms. If, for instance, a difference of potential or an electro-motive force of 15 volts between the two ends of a wire were able to maintain a current of 2 amperes through it, then its resistance would be $\frac{15}{2} = 7 \cdot 5$ ohms. But if the resulting current were only 2 milliamperes, then the resistance would be $\frac{15}{\cdot 002} = 7500$ ohms. With one of the instruments described in the preceding chapter, the current flowing may be measured, and in the next chapter we shall show how the difference of potential between any two points of a circuit may be measured in volts; and this method is perhaps the very best that can be devised for finding the value of very low resistances. But sometimes we know the maximum difference of potential or electro-motive force which a certain current generator can produce, and this knowledge will enable us in certain cases to calculate resistance after merely measuring current strength.

If we have a battery of which we know the electro-motive force, say 10 volts, and also the internal resistance, say 20^{ω}, we

may use it to send a current through the tangent galvanometer, G, and the unknown resistance, x, by joining them all in series as shown in fig. 76. Suppose the resulting current to be 20 milliamperes as measured by the tangent galvanometer, then we may find the *total* resistance of the whole circuit by dividing the

FIG. 76.



electro-motive force by the current. The total resistance will be $\frac{10}{\cdot 02} = 500^{\omega}$. Now, the resistance of the battery and galvanometer is 340^{ω}; if we subtract this from the total resistance we get the value of the unknown resistance, x, that is, $500 - 340 = 160$ ohms.

By using the thick wire coils of the galvanometer, and a battery of very low resistance as compared with that of the unknown resistance, no serious error will be made by ignoring the resistance of the battery and galvanometer, and regarding the unknown resistance as the total resistance of the circuit. Under these conditions a number of fairly high resistances may be easily compared, for the same electro-motive force will send through each a current which is inversely proportional to the resistance. Thus, if with three resistances, a, b, c, we get deflections of 30, 25, and 60 tangent divisions respectively, then, $a : b : c :: \frac{1}{30} : \frac{1}{25} : \frac{1}{60}$,

that is, $$a : b : c :: 10 : 12 : 5.$$

Presuming the galvanometer to be so adjusted that a deflection of 30 tangent divisions is obtained when a current of 10 milliamperes is passed through the thick wire coil, and the battery employed to have an electro-motive force of 2 volts, then the resistance of $a = \frac{2}{0{\cdot}01} = 200^{\omega}$. Therefore, the resistance of $b =$

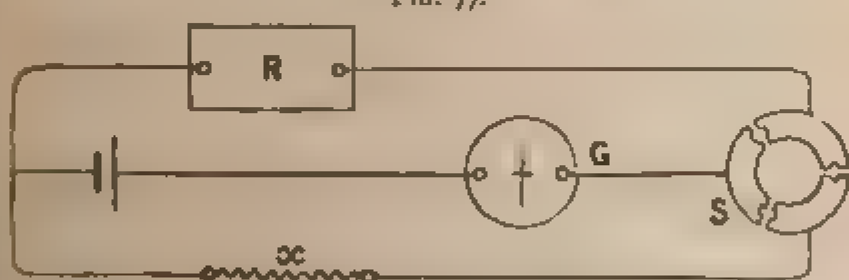
90", and of $c = 100$". As previously stated, however, the resistance of the battery and of the galvanometer must be taken into account, unless they are very low indeed as compared with the unknown resistances.

It should here be observed that in most of the tests to be described it is necessary that a set of resistances whose values are known exactly should be provided. The accuracy of the results obtained depends, in a very great measure, upon the accuracy of the values given to these resistances, so that great care should be exercised in their manufacture, measurement, and use. In Chapter II. some of the principal causes of inaccuracy were enlarged upon, and it was shown how, by avoiding them, a reliable set of resistance coils might be produced.

Assuming such a set of coils to be available, let us now discuss its utility in helping us to ascertain the resistance offered by other conductors.

If a wire, whose resistance we desire to ascertain, is joined up with a battery and galvanometer, the current flowing will deflect

Fig. 77.



the galvanometer needle through a certain angle; let this angle be accurately noted. Then, if the unknown resistance is removed from the circuit, and a box of coils of known resistance inserted in its place, this same deflection may be reproduced by varying the amount of resistance introduced by means of the plugs or arms, as described in Chapter II. The current then deflecting the needle will manifestly be exactly the same in strength as in the first case, and therefore (since the electro-motive force of the battery is unaltered) the total resistance of the circuit must be the same as before. Hence the resistance in the box is equal to the unknown resistance. A convenient way of taking this test is shown in Fig. 77. R is the set of resistance coils, x the unknown resist-

ance, and S is a three-way plug switch, consisting of three pieces of brass, any two of which may be joined together by inserting a brass plug in the holes provided for the purpose between them. By means of this switch, either x or R may be rapidly placed in circuit, and it is advisable to take a second test after R has been adjusted, to make sure that the electro-motive force of the battery has not been altered by polarisation and so have varied the value of the test. The galvanometer, G, should be a sensitive one; it should, in fact, under all conditions indicate the alteration in the current strength, caused by the addition or subtraction of the coil of lowest value in the resistance-box. As by this method the same deflection is reproduced, any form of galvanometer will answer the requirements, providing only that it is sufficiently sensitive.

Supposing, however, a tangent galvanometer and a battery, both of very low resistance, to be available, the currents which the battery can send through a known and an unknown resistance can be compared directly by the deflections of the galvanometer needle, for if there are, say, 50 tangent divisions in the first case and 45 in the second, and the known resistance is 32 ohms, then

$$45 : 50 :: 32 : x,$$

because the deflection in each case will be inversely proportional to the resistance in circuit. Hence, $x = 35\cdot\dot{5}$ ohms. The three-way plug switch may be used as in the last test, but both readings should be taken near the 'angle of maximum sensitiveness,' viz. 45°.

When, however, the resistances of the battery and galvanometer are comparatively high, their values must be known or ascertained, and allowed for in accordance with Ohm's law as follows: Let the resistance of the galvanometer, G, be 320^{ω}, that of the battery $r = 12^{\omega}$, and the known resistance $R = 560^{\omega}$; let the current with R in circuit (C_1) give 50 tangent divisions, and with x in circuit (C_2) give 45 tangent divisions.

Then, in the first case,

$$C_1 = \frac{E}{R + G + r}, \text{ whence } C_1(R + G + r) = E,$$

and in the second case,

$$C_2 = \frac{E}{x + G + r}, \text{ whence, also, } C_2(x + G + r) = E,$$

therefore $$C_2(x + G + r) = C_1(R + G + r),$$

whence $$x = \frac{C_1}{C_2}(R + G + r) - G - r.$$

Since $\frac{C_1}{C_2}$ is merely a ratio, the strength of the currents in milliamperes need not be known, the number of tangent divisions produced by the currents being inserted instead of C_1 and C_2. Inserting all the values, then, we get

$$x = \frac{50}{45}(560 + 320 + 12) - 320 - 12$$
$$x = 659·1 \text{ ohms.}$$

The resistance of the galvanometer is nearly always known and engraved on the instrument, but it is frequently necessary to measure the resistance of the battery at the time of making the test. To avoid this it is better to use a battery of very low resistance, and this may usually be obtained by joining up several sets in parallel.

The equation will then stand:

$$x = \frac{C_1}{C_2}(R + G) - G.$$

By inserting the values as before we can see the amount of the error caused in this case by ignoring the battery resistance of 12 ohms.

$$x = \frac{50}{45}(560 + 320) - 320$$
$$x = 657·7 \text{ ohms.}$$

The error is thus but 1·3 %; and it is not difficult to get a battery of only about 1 ohm resistance to send a sufficiently strong current for the above test, when the error would be negligibly small.

This method also provides us with a means of measuring the resistance of a galvanometer. For, let the second reading be

taken through a known resistance $K = 700^{\omega}$ instead of x, th ignoring the battery resistance, it follows that, as before,

$$C_1(R + G) = C_2(K + G)$$
$$C_1R + C_1G = C_2K + C_2G$$
$$G(C_1 - C_2) = C_2K - C_1R$$
$$G = \frac{C_2K - C_1R}{C_1 - C_2}.$$

Inserting the values we get

$$G = \frac{45 \times 700 - 50 \times 560}{50 - 45} = 700 \text{ ohms.}$$

With the same apparatus the internal resistance of the batt may be measured. For if the battery is joined up to the resistance coil of the galvanometer (three or twelve turns), pr cally the only resistance in the circuit will be that of the batte If possible, the adjustable magnet should be placed so that deflection is, say, 50 tangent divisions. Now, it will be evi that to *halve* the current flowing, the resistance in the circuit m be *doubled*. If, therefore, resistance R is inserted until the def tion falls from 50 to 25 divisions, the resistance R will be equ the resistance x of the battery.

Sometimes, however, the effect of the controlling magn insufficient to produce a convenient deflection, and it is necessary to introduce some resistance in the first test, say P, this purpose. Then

$$C = \frac{E}{x + P}, \text{ or } C(x + P) = E.$$

If, now, P is increased to R in order to halve the deflect and therefore halve the current strength,

then $$\frac{C}{2} = \frac{E}{x + R}, \text{ or } \frac{C}{2}(x + R) = E,$$

therefore $$\frac{C}{2}(x + R) = C(x + P),$$

whence $$x = R - 2P.$$

For instance, if with a low-resistance galvanometer it is fo ssary to insert 11 ohms in order to bring the deflection d divisions, and to increase this resistance to 31 ohm

order to make the deflection 30 divisions, then the resistance of the battery $x = 31 - 22 = 9$ ohms.

In some cases the resistance of a cell is so very low that it becomes a difficult matter to measure it with great accuracy. Secondary cells, especially, have not only a low resistance, but also a comparatively high E.M.F., so that some special method is necessary in dealing with them, if great accuracy is desired.

A very pretty method consists in allowing the cell to send a current through a low external resistance of known value, and then measuring the fall of potential which takes place along this resistance. This fall can be easily found by subtracting the external potential difference from the total E.M.F. developed. As the resistance of each portion of the circuit is proportional to the fall of potential taking place along it, the internal resistance of the cell can then be deduced. One of the hot-wire voltmeters (page 189), designed to indicate up to 2·5 volts, is a useful piece of apparatus for this work. The total E.M.F. of the cell can be measured by joining the voltmeter to the cell terminals, because the high resistance of the voltmeter allows only a feeble current to be generated, so feeble, in fact, that the fall of potential inside the cell is exceedingly low; whence the potential difference indicated is practically equal to the E.M.F. developed. If a second external conductor, but of low resistance, is also joined to the terminals of the cell, the total external resistance will be considerably reduced, and the fall of potential inside the battery proportionally increased, and a lower E.M.F. will be indicated by the voltmeter. Consequently, if we denote the total E.M.F. by E, the fall of potential in the external and internal portions of the circuit by P and p respectively, the resistance of the cell by r, and of the known external resistance by R, it is evident

$$\mathrm{E} - \mathrm{P} = p,$$

and

$$\mathrm{P} : p :: \mathrm{R} : r;$$

from which we get

$$r = \frac{p\,\mathrm{R}}{\mathrm{P}}.$$

When a battery of such cells is to be measured—say twenty—it is better to reverse nearly half of them—in this case, nine; then the resistance to be measured is that of twenty cells, while

and s is a three way plug switch, consisting of three pieces ..., any two of which may be joined together by inserting a plug in the holes provided for the purpose between them. By means of this switch, either x or R may be rapidly placed in circuit, and it is advisable to take a second test after R has been placed, to make sure that the electro-motive force of the battery has not been altered by polarisation and so have varied the value of the test. The galvanometer, G, should be a sensitive one; it should, in fact, under all conditions indicate the alteration in the current strength, caused by the addition or subtraction of the coil of lowest value in the resistance box. As by this method the same deflection is reproduced, any form of galvanometer will answer the requirements, providing only that it is sufficiently sensitive.

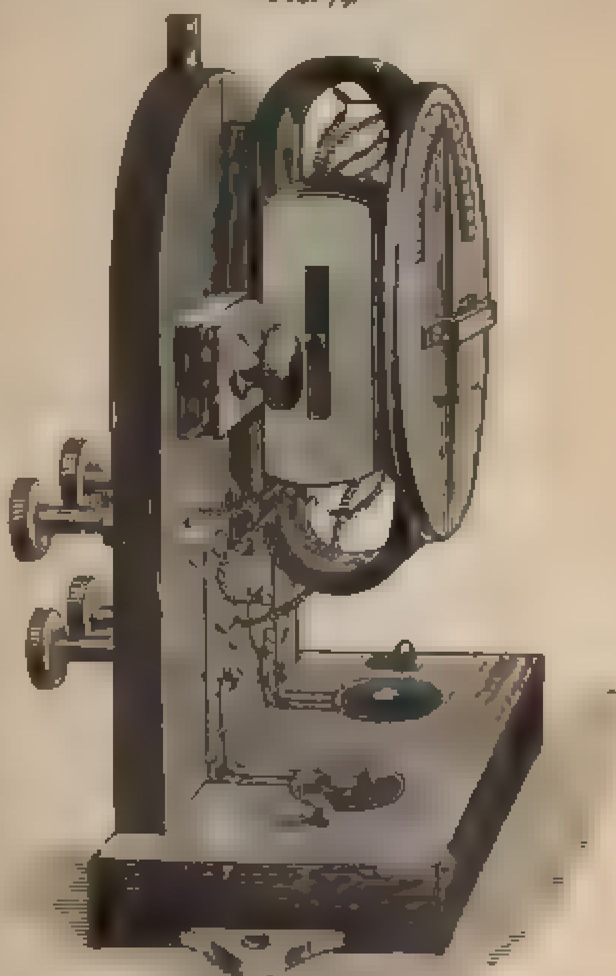
Supposing, however, a tangent galvanometer and a battery, ... of very low resistance, to be available, the currents which the battery can send through a known and an unknown resistance may be compared directly by the deflections of the galvanometer needle, for if there are, say, 50 tangent divisions in the first case, 45 in the second, and the known resistance is 32 oh...

$$45 : 50 :: 32 : x,$$

because the deflection in each case will be inversely ... the resistance in circuit. Hence, $x = 35.5$ oh... ... plug switch may be used as in the ... readings should be taken near the 'angle of ...' viz. 45°.

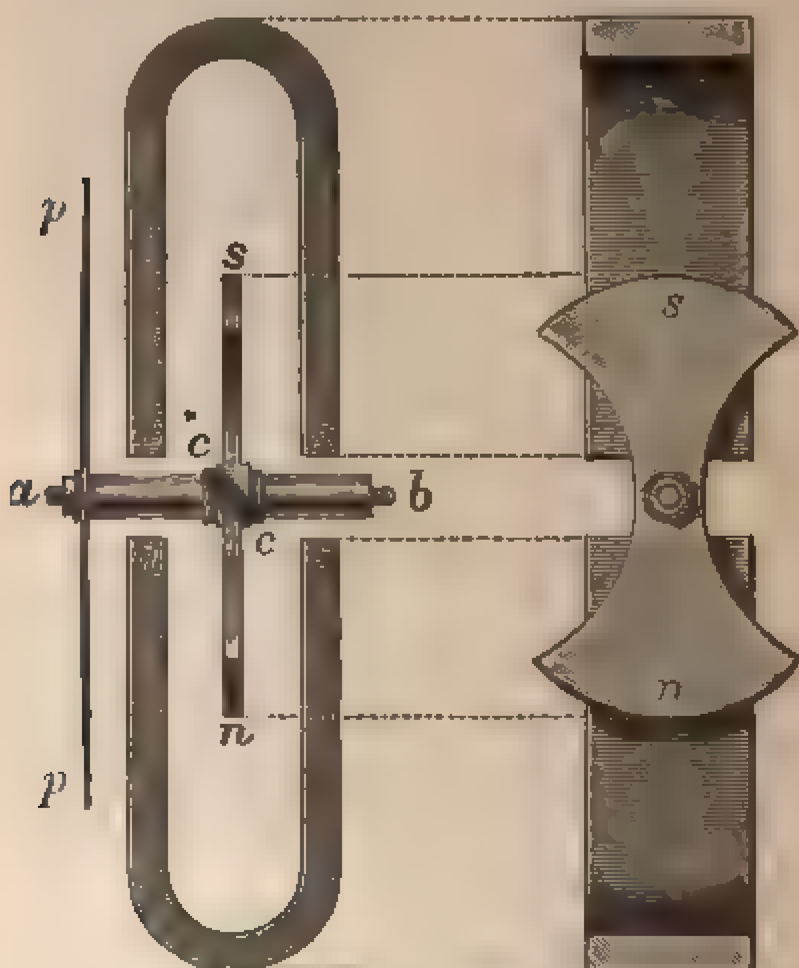
…int, and the whole is embraced by two horse-shoe magnets, …ced with their like poles adjacent, as shown in the figure. …hese magnets form a very strong field in the space in which the …indle lies. A large number of the lines of force pass through …e spindle, but when they reach the break in the iron at *cc* they …nd upwards through …e soft iron needle from …e side, and downwards …om the other side, the …sult being that the …eedle is a powerful mag…et with its north pole …ownwards. On the end … the spindle is fixed a …lackened brass pointer, …A, which, passing over … in front of a circular …al divided into degrees, …dicates the movements … the needle. The two …es, each offering 50$^\omega$ …sistance, are wound side … side over two separate …bbins, so that the cor…sponding portions of …ch wire are equally dis…sed in relation to the …edle and exert equal …gnetic effects upon it. This method is, of course, far in advance … the old instrument-makers' method of winding one wire alone … one bobbin and the other on another bobbin. The tests for a …fferential galvanometer are that, if powerful but equal currents … sent in opposite directions through the coils, no effect should … produced upon the needle: each coil used separately should …oduce equal but opposite deflections with the same current, and … coils should offer exactly the same resistance. The inner …ds of the two wires on the bobbins are respectively joined …gether and the other four ends connected to as many terminals

FIG. 79.



on the back of the instrument. This allows the current to be sent through the coils in several ways. First through one coil only, resistance 50^{ω}. Secondly, through both coils in series in such a direction that they act upon the needle in the same manner, when the resistance will be 100^{ω} and the deflective action doubled, provided the increase of resistance does not sensibly reduce the current. Thirdly, through both coils in

FIG. 80



parallel and in the same direction; the resistance in this case will be 25^{ω}, and the deflective action the same as that of *one* coil only. Fourthly, through both in parallel, but in opposite directions, when the needle should, as already stated, be unaffected. Lastly, through both coils in series in opposite directions, when the needle should also be unaffected. This last method of joining up is also useful for proving if the deflective effects of the two coils are

ual, for the same current passes through each irrespective of eir resistance.

Although the wires are wound side by side throughout, it is ry rarely that they are found to act with equal force on the eedle. There are three ways of attaining this result without fecting the resistance. The position on the bobbins of a portion either or both of the wires may be altered; or a part of the wire hich has the greater effect may be unwound and wound back on e bobbin in the opposite direction; or the stronger may be nwound until an exact balance is obtained, when the length so nwound may be coiled up in the base of the instrument, where, wound 'double,' it will have no effect on the needle.

The lower end of the needle is weighted, to keep it in the vertical osition and to restore it to that position on the cessation of the urrent; and the current acts against this weight when it deflects e needle. The *arm* at which this weight acts increases with the eflection of the needle, so that the angle of deflection cannot be oportional to the current strength. The relation between the o is, in fact, irregular, because of the peculiar shape of the eedle (shown in fig. 80), and because the field due to the current, though almost uniform inside the coil, is far from being so near e edges and just outside.

But at present we shall only consider the use of the instrument ith the needle at or near zero, at which point, it may be men-oned, it is most sensitive.

Provided with this instrument, a battery, and a set of resistance ils of sufficient range, we are in a position to rapidly measure known resistances.

Fig. 81 shows the best way of making the connections. G is e galvanometer, R a set of resistance coils, x the unknown sistance, and K a key for closing the battery circuit. On de-essing the key, the current will divide at $a\ c$, the junction of the o coils of the galvanometer, part passing through the coil $a\ b$ d R, and the remainder through the other coil $c\ d$ and x, back the battery.

Supposing R to be of less resistance than x, then a greater t of the current will pass through $a\ b$ and R than through $c\ d$ d x, consequently the needle will be deflected to one side. By

increasing R this excess of current will be diminished, and the deflection of the needle also decreased, until the needle again stands at zero. Then the currents flowing through both coils of the galvanometer are equal, and therefore the resistance of both branches must be equal, viz.

$$x + 50^{\omega} = R + 50^{\omega},$$

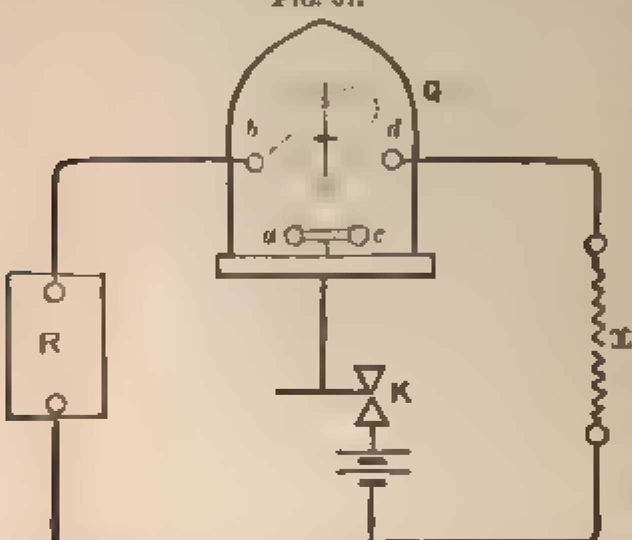
that is,

$$x = R.$$

By further increasing R the needle would be again deflected, but in the opposite direction to that previously obtained.

Before making a test it is advisable to find out and note in which direction the needle is deflected when R is too large or too small, so that immediately the needle moves to one side or the other we may know whether it is required to increase or decrease R.

FIG. 81.



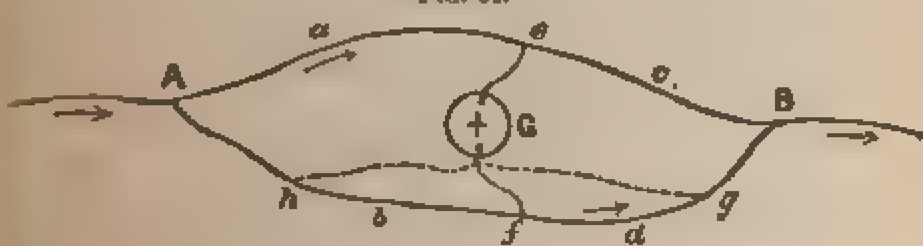
It may be necessary to measure resistances which are either higher or lower than any which can be inserted in the box R. The range can then be extended by shunting one coil of the galvanometer — say by a wire one-ninth of the resistance of the coil. Then, as only one-tenth of the current in that branch will pass through the galvanometer coil, a balance will be obtained when the total resistance in that branch is one-tenth of the resistance of the other. For instance, suppose the coil of the galvanometer connected to R to be so shunted, and a balance to be obtained, when the resistance in R amounted to 650 ; then the unknown resistance would be $6{,}500^{\omega}$ nearly. We say nearly, because, in order to obtain a perfectly accurate result, compensating resistance must be inserted to make the resistance of the shunted galvanometer coil equal to 50^{ω}, as explained in the preceding chapter.

In measuring electro-magnets or any single wound coils, a sudden jerk of the needle, due to self-induction (see Chapter VII.),

ll always be noticed on making and breaking the circuit. In ch cases care should be taken to see that the needle rests at zero hen no current is flowing, and then the key should be depressed d the adjustments made with a steady uninterrupted current til the needle again comes to zero.

The differential galvanometer, although a first-rate instrument r comparing two resistances by the equalisation method, loses in mplicity and rapidity when shunts have to be used and allowed for. y means, however, of a piece of apparatus known as the 'Wheatone Bridge,' the value of any resistance can be readily measured. he principle of this invaluable apparatus is very simple, and is plained by the diagram (fig. 82). Let us suppose two wires, *a e c* B and A *b d* B, either equal or unequal in resistance, to be

Fig. 82.



ined up in parallel and a current sent through or divided between em, as shown in the figure. The current will, as already exained, divide itself between the two wires inversely as their sistances, but, for our present purpose, the current strength is a tter of little or no importance.

If, now, one end of a galvanometer coil, G, is joined to any int, *e*, in one wire, and the other end to a point, *g*, in the her, very near to the junction B, a deflection of the galvanoeter needle will be observed, indicating a current flowing from to *g*.

On removing the galvanometer wire from *g* and joining it to other point, *h*, also in the second wire, but very near to A, the lvanometer will again indicate a current, but flowing in the verse direction, viz. from *h* to *e*. If contact were successively ade at points along the wire A *b d* B farther from A, the current uld become feebler and feebler until, finally, a point, *f*, would be nd at which the needle would not be affected at all, showing e absence of a current through the galvanometer.

There can be but one explanation to these experiments. It was clearly laid down and demonstrated in Chapter II. that whenever a current of electricity flows, it does so invariably in virtue of a difference of potential between the extremities of the conductor through which it flows, and, conversely, whenever the extremities of a conductor are at different potentials a current flows through it. These two facts must never be lost sight of, for they constitute the key to a host of electrical phenomena and problems. Inasmuch, then, as it was seen, by the evidence of the galvanometer, G, fig. 82, that a current passed through it when its terminals were connected to the points *e* and *g*, and to the points *e* and *h*, the current or currents flowed as a consequence of a difference of potential between those points. And the absence of a current on connecting the points *e* and *f* together is an equally clear proof that those two points were at the same or equal potentials. If we suppose A to be at a higher potential than B, and connect the galvanometer directly to those points, so that it shall share the current arriving at A, the needle will be deflected to one side or the other, the particular deflection being governed by the direction of the current round the needle. Let us suppose the deflection to be to the right. Then, on connecting the galvanometer to A and *g*, or even to *e* and *g*, the deflection will also be to the right, and will establish the fact that the potential at *e* is higher than that at *g*. On the other hand, the opposite deflection which is obtained when the galvanometer is connected to *e* and *h* affords ample proof that the potential at *h* is higher than that at *e*. Now, as the ends of the two wires at A are always at the same potential, and as the ends at B are also at the same potential, although lower than that at A, it follows that the fall of potential along A *a c* B must equal that along A *b d* B. It also follows that if we fix upon any one point in either of the wires, there must always be a point somewhere in the other wire which will be at exactly the same potential, and if these two points are connected together no current can possibly flow between them. Herein is the underlying principle of the Wheatstone bridge.

We must now endeavour to discover what relation, if any, exists between the resistances of the four sections into which these wires are divided. Let the resistance of the section between A and

lenoted by a, that between A and f by b, between e and B by l between f and B by d.

he difference of potential between A and e is equal to that een A and f; call this P_1.

gain, the difference of potential between e and B is equal to etween f and B; call this P_2.

ow we have seen that in every case (since by Ohm's law CR) the difference of potential between any two points is equal e current flowing, multiplied by the resistance of the con- r between those points.

uppose the current flowing in the upper branch, A e B, to be C_1, hat in the lower branch, A f B, to be C_2.

t $$P_1 = C_1 \times a;$$

$$P_1 = C_2 \times b;$$

efore $$C_1 \times a = C_2 \times b,$$

$$\frac{a}{b} = \frac{C_2}{C_1}.$$

n, $$P_2 = C_1 \times c,$$

$$P_2 = C_2 \times d,$$

efore $$C_1 \times c = C_2 \times d,$$

$$\frac{c}{d} = \frac{C_2}{C_1}.$$

t $\frac{a}{b}$ is likewise equal to $\frac{C_2}{C_1}$;

ntly $$\frac{a}{b} = \frac{c}{d}$$

is the relation between the re which we sought and we might, in the sam ve that it holds her cases where the resistan ferent values.

tion may also be viewed er standpoint. ntial along a conductor nal to its re- ersely, the resistanc uctor is pro- potential which ta ng it. Now, along the two 82) is equal at e is equal nd the fall

The stretched wire must be of considerable resistance so as to make the fall of potential per unit of length appreciable, and it should be of some hard durable metal, otherwise it would become worn by the slider and its uniformity of resistance destroyed. For these reasons the wire should be made of German silver, platinum silver, or platinoid. A key should be inserted in the battery circuit, to prevent the current being kept on longer than necessary, and heating the wires. Extra resistance in the galvanometer or battery circuits introduces no error, merely reducing the sensitiveness of the arrangement. But it is important to secure good clean connections in the other branches, as any resistance introduced there might cause a great error in the result. To obtain the best results the resistance of the battery should be low and its E.M.F. high; the resistances in the arms of the bridge should not differ very greatly, and the galvanometer must, of course, be sufficiently delicate to indicate the difference of potential caused by moving the slider through the shortest measurable distance. But the length of the wire on the galvanometer must not be indefinitely increased to attain this result, otherwise the resistance so added reduces the current in a greater proportion than the deflective effect is increased.

FIG. 85.

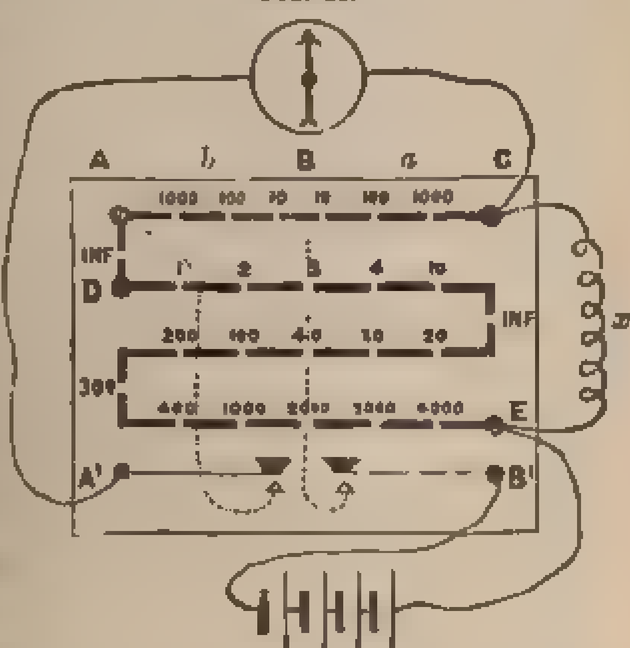
There is, in fact, for every separate test, a certain resistance which it would be best to give the galvanometer. In practice, however, we can do no more than wind the galvanometer in such a manner as will make it best suited to the average conditions under which it will be employed. For an ordinary slide wire bridge the galvanometer resistance should not greatly exceed one ohm.

The slide-wire bridge answers well in a laboratory, and is

exceedingly valuable for measuring low resistances. A more practical form of the Wheatstone bridge and one which is very largely used for general work is shown in fig. 85, and its connections in fig. 86.

There is no exposed stretched wire here, but all the resistances are placed in a mahogany box with an ebonite top, their ends being connected to brass blocks fitted with plugs as in the case of any ordinary resistance-box. These resistance coils are measured with extreme care, and the value of each in ohms is marked (often indistinctly, by the way) upon the ebonite. Double terminal screws are employed to avoid risk of resistance being introduced by the careless connection of two wires on to one terminal. In the general view it will be seen that there are two keys, each, when depressed, making contact with a metal stud; these keys are marked A′ B′ in fig. 86. A terminal screw is connected to each key, and to the right hand one

FIG. 86.



is joined the zinc pole of the testing battery. The stud under this key is connected beneath the ebonite cover to the brass block B in the middle of the back row of resistances, so that the zinc pole of the battery is joined to this block when the right-hand key is depressed. It is at this point then, corresponding to B, the junction of Q and S in fig. 83, that the current divides, and on either side are three coils of 10, 100, and 1,000 ohms respectively, any or all of which can be inserted at pleasure. At each end of this row of coils is a terminal screw, and the galvanometer is joined up to these points. But, as we have seen, it is necessary to have a key in the galvanometer circuit, and it is very convenient to place both keys close together, as shown. One wire from the galvanometer is therefore brought to terminal

A′—that is, to the left-hand key—and the stud under this key is connected to terminal A, as shown by the dotted line. Therefore, when A′ is depressed, this side of the galvanometer is joined to terminal A. The other side of the galvanometer goes direct to terminal C. The two 'arms' of the bridge, B A and B C, correspond to S and Q in fig. 83, and the arm marked R in that figure here consists of a number of coils, ranging from 1 ohm to 4,000 ohms, placed between the terminals D and E. We have thus three arms of the bridge of known values, and the fourth, or unknown resistance, x, is placed between terminals C and E. The copper pole of the battery is brought direct to terminal E, which corresponds to the junction of P and R in fig. 83. Between the arms B A and D E—that is, between the terminals B and D—is a space marked 'infinity.' There is no coil connected to the two blocks at this point, so that the resistance is infinite, that is, the circuit is disconnected when the plug is removed. This arrangement is exceedingly useful, for it is possible to increase the range of measurement considerably, by removing the plug and inserting an extra box of coils in the circuit here; and further, it is often convenient, in some tests, to be able to separate the coils into two independent sets. There is a second 'infinity plug' between the 10 and 20 ohm coils, and when using the apparatus simply as a set of resistance coils these plugs may be used as keys for disconnecting or joining up the circuit.

Now, suppose the bridge to be properly joined up, with an unknown resistance x, the value of which it is desired to find, between C and E.

It is clear that A and C are the points which we want, by adjusting the various resistances, to bring to the same potential, and the galvanometer is connected to these points so as to indicate when this result is attained. We begin by inserting some resistance in the arms B A and B C, say 100 ohms in each. These resistances are not again altered during the measurement, but the adjustment is made by varying the amount of resistance in the arm D E until the galvanometer shows that a balance has been obtained. When this happens the value of the unknown resistance, x, is equal to the amount which has been inserted in the arm D E. Much time may be saved and greater accuracy ensured

by taking a test methodically, and the following points should be attended to. Before starting it should be ascertained that the plugs are firmly in their places and that all the connections at the terminals are good, and to ensure this it is advisable to take advantage of the double terminals provided, and place only one wire on each screw. The galvanometer having been placed in a position convenient for the experimenter, some coils in each of the three arms must be put into circuit, the amount in the arms D E being made as near the unknown resistance as can be guessed. The right hand key should be depressed and then, a moment afterwards, the left hand key, and the galvanometer observed; probably the latter will indicate the passage of a current, and it should always be found which way the needle moves when the resistance in the arm D E is, say, too high. If that is done, one can see, immediately the needle moves, whether it is necessary to increase or reduce the resistance in D E in order to get a balance. This is much quicker than obtaining the balance at random. The galvanometer key must only be lightly tapped so as to just indicate in which direction the resistance must be varied, until a balance is nearly obtained, when it may be held down for a longer period. This prevents a heavy current being passed through the galvanometer, and the student will hardly require warning that if the battery is kept on too long the coils will become more or less heated and their resistance varied. It should also be borne in mind that with a very delicately made instrument a suddenly applied heavy current is likely to injure the needle or the pivot.

We considered above the simple case when the resistances of the arms B A, B C were equal, but the bridge is not always used under these conditions.

If, for instance, the unknown resistance is comparatively low and we desire to measure it to within a fraction of an ohm, it is then necessary to have these arms of unequal resistance; we should, in fact, make B A 100 ohms and B C 10 ohms. Then, if a balance were obtained with 13 ohms in D E, x would be equal to 1·3 ohms. For, by the principle of the bridge,

$$x = \frac{\text{BC} \times \text{DE}}{\text{BA}} = \frac{10 \times 13}{100} = 1{\cdot}3.$$

And by using 1,000 ohms in B A and 10 in B C, measurements to within $\frac{1}{100}$ of an ohm might be made.

When the unknown resistance is very high, then the ratio must be reversed, taking, say, 10" in B A, and 1,000" in B C. If, now, a balance is obtained with 1,309 ohms in D E, then

$$x = \frac{1000}{10} \times 1309 = 130900 \text{ ohms.}$$

When using this ratio it is not always possible to obtain a perfect balance and so determine the unknown resistance exactly, because the lowest unit in the arm D E is 1 ohm, and this is equivalent to 100 ohms in the unknown resistance. For instance, if in the last test the unknown resistance were 130,925 ohms, it would be necessary to increase the resistance in D E by a quarter of an ohm in order to get a perfect balance, and this fraction is not at our disposal. A supplementary set of resistances having fractional values may be inserted between the terminals A and D, provided that the arrangement is sufficiently sensitive for the galvanometer to respond to the change produced by these fractions of an ohm; but for general work it is sufficient to know the value of a very high resistance to within 10 or 20 ohms, and this can always be estimated by observing the movements of the needle when the resistance in D E is less than 1 ohm too high and less than 1 ohm too low.

It may be remarked that the efficiency of the Wheatstone bridge is reduced by the injudicious choice of a battery, more frequently than by any other cause.

The point to be borne in mind is, that a considerable fall of potential is necessary along the arms of the bridge, that is, between the points A and B in fig. 82. The greater the difference of potential between these points, the greater will be the effect on the galvanometer needle for a given change in any of the resistances, and therefore the higher the degree of accuracy to which we can measure. Now, suppose the bridge to be of the slide-wire form, and the resistance of the arms between A and B to be 2 ohms. If we employ a battery of 10 Daniell cells, having a resistance of · ohms per cell, the potential difference between A and B will be ·siderably less than three-quarters of a volt, all the rest of the

fall taking place inside the battery. A single Grove cell, having a resistance of ·2ω, could maintain about 1·8 volts under similar conditions, although its E.M.F. is only one-fifth of that of the Daniell battery. This clearly shows the evil effect of resistance in the battery, and it is evident that when the resistances in the bridge are low, the battery employed, while having a sufficiently high E.M.F., *must* have a very low internal resistance. When, however, the resistances are high, resistance in the battery circuit is not so harmful (as the fall of potential in any part of a circuit is directly proportional to the resistance of that part), and a battery of Daniell cells may be employed. The E.M.F. of the battery is often kept unnecessarily low to avoid a strong current heating the coils; there is, of course, a limit, but by a skilful manipulation of the keys provided, the time during which the current need be kept on is so very short that the heating is inappreciable. We have remarked that it is better to depress the battery key first, and allow the current to become steady before tapping the left-hand key and throwing the galvanometer in circuit. A very short time is sufficient for this, but extra care should be taken that it is done when the unknown resistance is an electro magnet, or any coil which is liable to the phenomenon of 'self induction' (see Chapter VII.), or when it has any 'electrostatic capacity,'[1] as in the case of a telegraph line or cable, otherwise the needle will move violently, although the actual resistance may be truly balanced. To enable the student to understand how the nature of the resistance can cause the potential at any two points to be widely different when the current is starting or stopping, and yet equal when it is steady, we may employ an analogy. Suppose we have two equal iron water pipes joined up as in fig. 82, with some piece of apparatus to indicate a difference or equality of pressure, in the place of the galvanometer, the points *e* and *f* being at equal distances from A or B. Then, the pipes being equal in all respects, the pressure at *e* and *f* will always be equal, no matter how the difference of pressure at A and B may be varied. If, now, one branch, A *f* B, is replaced by a very flexible india-rubber

[1] The scope of this work will not permit us to deal with this branch of the subject; 'electrostatic induction' has seldom to be contended with by the electric-light engineer.

pipe of similar dimensions, this no longer holds good. Suppose the pipes to be empty and then water at a high pressure to be forced in at A; the pressure at *e* will rise quicker than at *f* because the flexible pipe expands, and this occupies a short time. When the expansion has reached its limit the pressures at *e* and *f* are equal, but on suddenly stopping the flow at A, the pressure at *f* becomes higher than at *e* for a brief moment owing to the contraction of the pipe.

Somewhat similarly, as we shall see later on, a current of electricity can never rise to its full value, nor die away instantaneously; for this reason, the coils of the bridge are so wound that in them the rise or fall is very rapid, and when the unknown resistance is such that the rise or fall takes place at a different rate, the current must be allowed to become steady before the second key is closed.

The peculiar method of winding the bridge coils is also useful in preventing any direct action, which might be caused by the current circulating in them, being produced upon the galvanometer needle. When an electro-magnet is being measured, the galvanometer must be placed far enough away to avoid its being affected when the current is passed through the electro-magnet. When there is any reason to suppose that some such effect as this exists, the battery key should be closed and opened several times, the galvanometer key being left open and the needle watched. If it moves at all, we have proof positive that some portion of the apparatus is producing a disturbing effect upon the galvanometer.

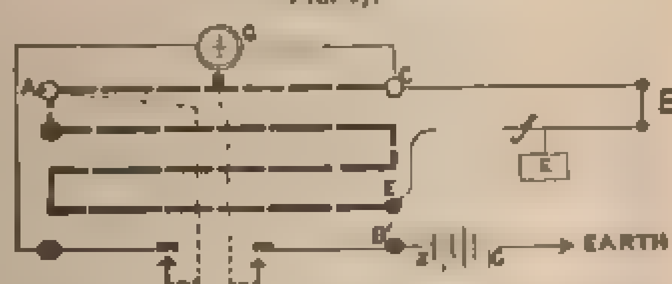
We will describe one other test, known as the 'Loop test,' which is rather interesting, and may prove useful to an electric-light engineer.

When both ends of the unknown resistance are not easily accessible, it may be measured by joining one end to the terminal C, and connecting the distant end to earth. The terminal E—that is, the junction of the arm D E and the copper pole of the battery are also put to earth, and then the test can be made in the usual manner, because the two earth-connected points are at the same potential, and behave in precisely the same way that they would if they were joined to a common terminal. A leakage sometimes occurs in a covered wire or cable, which allows more

or less of the current to escape to earth, provided some other point of the system is also earthed. It is necessary to be able to determine the distance of such a 'fault,' or point of leakage, and this might easily be done by disconnecting the line beyond it, and then, treating the fault as an earth, measuring the resistance of the wire up to this earth as described above.

It rarely happens, however, that any fault develops which does not offer considerable resistance to the passage of the current to earth, and as the amount of this resistance is never known it cannot be allowed for. Further, the resistance frequently varies so rapidly that it is not possible to obtain a balance at all, and some different arrangement of the bridge is necessary. We have seen that in the battery circuit extra resistance, and even variable resistance, causes no error in the result, although it reduces the sensitiveness of the bridge; and if this variable earth fault can be placed in the battery circuit, we can ignore its resistance altogether. This can readily be done if both ends of the wire are accessible; if not, it is necessary to have a second or return wire, and connect the distant ends of the two together. This arrangement is shown in fig. 87. The copper pole of the battery is put to earth, the zinc pole being always joined to line in fault-testing, as the current in that direction—usually by an electrolytic effect—decreases the resistance of the fault. E B is the faulty wire, the fault being shown at *f*. C B is the sound wire by means of which we reach the other end of the faulty wire, the two being looped together at B. The good wire is joined to terminal C, and the faulty one to E. On depressing the battery key the current flows through the bridge and the lines, finding earth at the fault, and a balance can be obtained in the usual way. Let R be the resistance inserted in A E, and let x represent the unknown resistance of the faulty wire from E to the fault at *f*. Then the total resistance of this arm of the bridge is $R + x$. The other arm consists of the sound wire, C B, and that portion of the faulty

Fig. 87.



wire from B to *f*. Let the total resistance of this arm be called *y*. Let *a* be the resistance in B C, and *b* that in B A, then

$$a : y :: b : R + x,$$

that is,

$$y = \frac{a}{b} \times (R + x) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).$$

We have here two unknown quantities, *x* and *y*, and must therefore get a second simple equation in order to eliminate one of them. It is clear that the total resistance of the two lines is $x + y$, and usually this is known; if not, it can be measured by joining up the bridge in the ordinary way (that is, connecting the copper pole of the battery to terminal E), and measuring the resistance of the loop as if no fault existed; for there will then be no leakage at the fault, as no other part of the system is earthed. Suppose the resistance thus found to be L ohms, then

$$x + y = L;$$

therefore

$$y = L - x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

Therefore, from equation (1),

$$\frac{a}{b} \times (R + x) = L - x;$$

therefore

$$x = \frac{b\,L - a\,R}{a + b}.$$

If we make $a = b$, as is frequently done in this test, then, evidently,

$$R + x = L - x,$$

and

$$x = \frac{L - R}{2};$$

or, we simply subtract the resistance in A E from that of the two lines, and, dividing by 2, obtain the value of *x*.

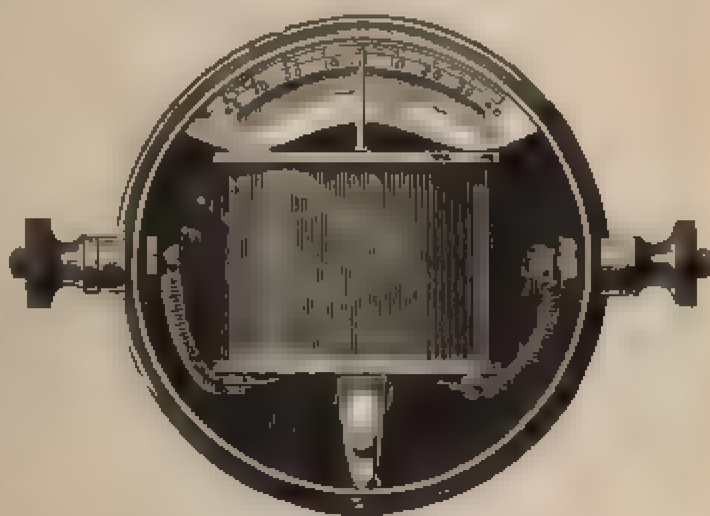
Now, *x* is the resistance in ohms from E to the fault; the length of the wire E B is known, and therefore its resistance per mile, or any other unit of length, is known. Thus we can at once ascertain the distance of the fault in miles or yards by dividing *x* by the resistance per mile or per yard.

The galvanometer used with the form of bridge above described has a resistance of 800 ohms; it is shown in fig. 88, and is a very good instrument—portable, yet capable of giving evidence of a

very small potential difference. When joined up in circuit with a resistance of 20,000 ohms, and a single Daniell cell (the current then being about one twenty-thousandth of an ampere), it will give a deflection of 25°.

The coil consists of many turns of fine silk-covered wire, wound on a single brass bobbin. The needle, which is pivoted, lies exactly in the centre of the coil, and is quite covered by it. At right angles to the needle is fixed a pointer, which projects from the coil, and, passing over a scale and a strip of looking-glass, indicates the slightest movement of the needle. A lever is provided for lifting the needle from its pivot when not in use, and each end of the coil is connected to a terminal which is insulated from the brass casing by ebonite. The features in the design of the instrument which enable it to respond to very feeble currents are the great length of wire employed, the nearness of this wire to the needle, and the lightness and excellent pivoting of the needle, which allow it to move easily.

FIG. 88.



Another form of Wheatstone bridge is shown in fig. 89. This has a very great range, and some of its coils are joined up differently to those in the apparatus last described.

The two 'ratio arms' each consist of five coils, of 1, 10, 100, 1,000, and 10,000 ohms resistance, and are connected up in the usual manner. The arm which is varied in balancing is divided into four sets of coils, each set consisting of nine *equal* coils. The resistance of each coil in the first set is 1^{ω}, in the second 10^{ω}, in the third 100^{ω}, and in the fourth $1{,}000^{\omega}$. Sometimes a fifth set of $\cdot 1^{\omega}$ each is added. In the figure will be seen 10 brass blocks surrounding a circular central one, with which they can be separately connected by a plug. The block partly hidden by the

plug is numbered 0, and this block is connected to the centre of the next dial. Between each of these numbered blocks (except 9 and 0) one of the equal resistance coils is placed, and by means of the plug any number of them can be brought into circuit. For instance, if the block numbered 5 is so joined to the centre plate, the current passes from the plate by means of the plug, and through five of the coils round to the block number 0, which is joined to the next centre plate, or, in the case of the last dial, to a terminal screw. Some tests can be very quickly made with this form of bridge, and the result seen at a glance. Of course, the circuit is disconnected in the variable arm every time a plug is shifted, if only one plug is used for each dial.

FIG. 89

One of the most important uses to which the instruments and methods described in this chapter can be applied, is that of determining the 'insulation resistance' of an electrical circuit, which is accomplished by entirely disconnecting the remote ends of the conductors, and then measuring the resistance offered by the insulating material to the leakage of a current from one conductor to another, or to earth. Should this resistance fall below a certain prearranged standard, evidence will be afforded of the existence of a fault which requires to be localised and removed forthwith. The insulation of the conductors having been proved, the switches and other fittings may then be joined up, when a second careful test should be made, which in most cases will

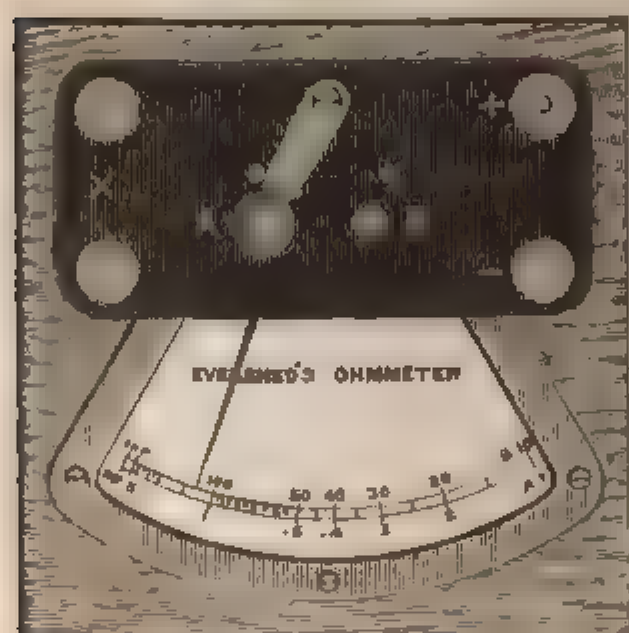
reveal the fact that the insulation resistance has fallen considerably, often as much as 50 per cent, due mainly to surface leakage. By testing the insulation resistance of the conductors separately, a ready means is afforded of determining whether a particular fault is in the covering of the wire, or in the fittings, and it may be observed that a certain amount of leakage at the fittings should be deemed of less importance than an equal or even a smaller leakage in the conductor covering; for whereas in the former case it is mostly due to moisture and therefore not liable to any serious increase, in the latter case it indicates a damaged or inferior insulating material, a fault which will most assuredly develop under the continued electrical stress.

In electric light installations very heavy currents and rather high E.M.F.'s. are frequently employed, which might cause serious damage to life and property should the insulation at any point be allowed to fall below a certain standard or become in any way faulty, and any such fault would, of course, also impair the efficiency of the lighting, to say nothing of the energy wasted. Similar conditions obtain with any system of electrical conductors and fittings for any purpose whatever, and it is necessary that some convenient means should be available for efficiently testing the whole installation, under conditions equally trying to the maximum stress which it will be called upon to sustain in practice. Especially must the source of electrical power employed for the test be able to develop an E.M.F. at least equal to the maximum intended to be used, otherwise there will be considerable risk that small incipient faults will not be shown up during the test, and will only become manifest when the circuit is in practical use, and when, therefore, the greatest inconvenience, and possibly damage also, will result

As 100 volts is the lowest E.M.F. which generally obtains in practice, it is evident that the employment of batteries for testing would be exceedingly inconvenient, so much so, in fact that an efficient test is frequently shirked. A small magneto machine, such as we shall describe in a subsequent chapter, is far more convenient and portable, but it is hardly suitable for use with the apparatus ordinarily constructed for the measurement of

resistance. Within the last few months an instrument has been introduced by Messrs. Goolden which answers admirably, and, in fact, is designed to work with such a machine. It is called an 'ohmmeter,' from the fact that its pointer indicates directly the number of ohms in the resistance under measurement. In practice, however, one does not actually require to find the exact resistance of an installation within a few ohms more or less. It is, indeed, sufficient if the apparatus can assure us whether, under the stress produced by a sufficiently high E.M.F., the insulation is above or below the standard, which we may here suppose to be fixed at 1 megohm (a million ohms). If below this standard, the circuit should be tested in sections until the fault is localised. The apparatus in question can promptly and decidedly indicate whether a resistance is above one megohm or below it, and supposing it to be above, of course the installation is passed as satisfactory. A top view of the instrument is given in fig. 90. When the small switch is placed as shown on the contact A, the outer scale A is to be used, but by shifting the switch to the contact B, a coil is shunted, thus enabling the lower resistances to be measured by readings on the inner scale, B. The wires from the source of E.M.F. (the magneto machine) are attached to the terminals marked + and —, while wires leading from the resistance to be measured are attached to the other terminals marked ×.

FIG. 90.



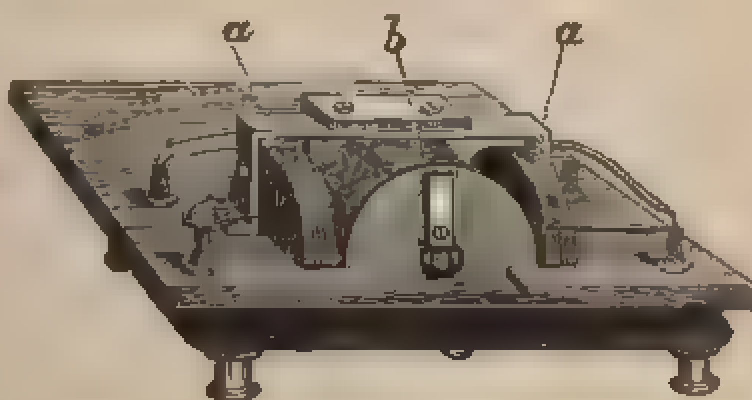
It is not possible to measure the higher resistances with certainty to within 100 ohms or so, but this is immaterial, as, if the insulation is below the standard, it matters little whether it is 700,000 or 700,200 ohms.

Fig. 91 is a view of the interior of the instrument turned

upside down, the working parts there shown being placed under the ebonite slab on which the switch and terminals are fixed.

The scale plate is shown in fig. 90. The inner of the two scales is marked in divisions of 1,000 ohms from ten thousand up to infinity, while the outer reads in megohms from 0·1 megohm to infinity, the scale being fairly open up to 5 megohms. In the construction of the instrument there are three coils (shown in plan in fig. 92); two of them, *a a*, are placed with their planes parallel and

Fig. 91.



are joined in series, while the third, *b*, is placed between and with its plane and magnetic axis at right angles to those of the coils *a a*. The inner coil, *b*, is shaped so as to allow the pointer to travel through a comparatively wide range. The figure, which is drawn from the under side, also shows the small steel needle in its zero position. This needle is then lying in the centre of the coil *b*, and along the common axis of the coils *a a*. In the case underneath it is placed a small weak bar magnet which adjusts itself so as always to neutralise the effect of the earth's magnetism, and, consequently, the only magnetic forces acting upon the needle are those due to the currents in the coils. A current passing through the coils *a a*, which are of high resistance, tends to keep the magnetic needle in the position shown, that is, at zero, with its length along the common axis of the coils *a a*. But its length is then parallel to the plane of the coil *b*, and any current

Fig. 92.

which was described in Chapter III. If carefully used it will remain constant for years; but, as it polarises quickly, it should not be allowed to send so strong a current as even 1 milliampere, and, if possible, should only be used in those tests, to be presently described, in which the batteries are tested when they are not sending any current at all, but simply maintaining a potential difference. A rather serious drawback to this cell is, that its E.M.F. varies with a change of temperature, falling as the temperature rises; and although, the temperature being known, the variation of E.M.F. can be allowed for, such calculations are very inconvenient and take time. Its E.M.F. at 15° Centigrade is 1·435 volts.

The Daniell cell when in good condition does not polarise, even when developing a strong current, and it has the further advantage that a considerable variation of temperature makes little or no difference in its E.M.F. It is, therefore, a good standard for use in the workshop, and any form of Daniell cell in first-rate order may be employed, especially when the tests are independent of the battery resistance. But it must be remembered that the plates should be bright and clean, the supply of crystals in the copper cell plentiful, and the solution in the zinc cell half saturated. The E.M.F. then is 1·079 volts.

Since the current which a battery can develop is proportional to its E.M.F., it is evident that the E.M.F. of two batteries can be compared by observing the currents which they send through circuits offering *equal* resistances. The Daniell cell should be used as the standard in this case, and if it gives on a tangent galvanometer 25 divisions deflection through a total resistance of, say, 1,000$^\omega$, while another cell or battery gives 62·5 divisions through the same resistance, then

$$25 : 62{\cdot}5 :: \mathrm{E} : x,$$

where E is the E.M.F. of the standard cell, and x that of the battery under measurement.

Therefore $$x = \frac{62{\cdot}5 \times 1{\cdot}079}{25} = 2{\cdot}7 \text{ volts nearly.}$$

One objection to this method is, that it is necessary to know the resistance of the batteries, in order that the total resistance

ay be made the same in both cases; but if the resistance of the ternal circuit is comparatively high, then the resistance of the tteries may be ignored.

In this simple method, the resistance is kept constant, while e current varies. The various currents are then measured and e relative E.M.F. deduced therefrom.

But it is also possible to compare electro-motive forces by rying the resistance and keeping the current constant, in which se the electro-motive force is proportional to the resistance; for, e higher the E.M.F., the greater is the resistance through which can send a given current. One great advantage in connection ith this method is, that any kind of galvanometer which may available can be employed, because the same deflection is oduced in every case. In order, therefore, to compare the M.F. of any battery x, with the standard cell E, we should join p the standard cell in circuit with a rheostat and galvanometer, rying the resistance so as to obtain a convenient deflection of, say, 5°, and noting carefully the total resistance, R_1, in circuit. The ttery to be tested should next be joined up, and the resistance tered, say, to R_2, so as to reproduce the deflection of 45°.

Then $$x : E :: R_2 : R_1 \text{ or } x = \frac{E R_2}{R_1}.$$

In this test, too, the resistances of the standard cell, the battery, nd the galvanometer must be known and taken into account nless the resistance in the rheostat is comparatively high, when hese other resistances may be ignored.

But by a simple extension of this method, it is possible to btain an accurate result without knowing either of these three esistances. The process consists in first joining up the standard ell, E, in the same manner as in the previous test, and then djusting the rheostat until a deflection of, say, 45° is obtained. The resistance should then be increased until the deflection falls o, say, 35°, noting carefully the exact number of ohms, P, by which the resistance is increased, in order to bring about the eduction in the deflection. The battery, whose electro-motive orce, x, it is desired to measure, must now be substituted for the andard cell, and the resistance again adjusted until the deflection f 45° is reproduced. This resistance should then be increased

by, say, Q ohms until the deflection is once more 35°. Then, as shown below,

$$x : E :: Q : P, \text{ or } x = E\frac{Q}{P} \text{ volts.}$$

To take an example. If with the Daniell cell as a standard the insertion of 720 ohms reduces the deflection 10°, that is to say, from 45° to 35°, and when the battery is substituted it is found necessary to add 2,300 ohms to reduce the deflection through the same 10°, then

$$x = 1{\cdot}079 \times \frac{2300}{720} = 3{\cdot}446 \text{ volts nearly.}$$

This is a very good method, and it is interesting and instructive to observe how the battery and galvanometer resistances are eliminated. This may be shown by Ohm's law as follows:

Let G be the resistance of the galvanometer, r_1 the internal resistance of the standard cell, and R the resistance in the rheostat when the needle is deflected through 45° by the current whose strength is indicated by C_1, then

$$C_1 = \frac{E}{R_1 + r_1 + G}.$$

Also let r_2 be the resistance of the battery whose E.M.F. is to be deduced, and R_2 the resistance in the rheostat necessary to reproduce the deflection of 45°, or when the current strength can again be indicated by C_1, then

$$C_1 = \frac{x}{R_2 + r_2 + G},$$

therefore $$\frac{E}{R_1 + r_1 + G} = \frac{x}{R_2 + r_2 + G}$$

$$E(R_2 + r_2 + G) = x(R_1 + r_1 + G) \quad . \quad . \quad . \quad . \quad (1).$$

When the resistances R_1 and R_2 are increased by P and Q respectively to obtain the deflection of 35° which will correspond to a current strength which can be called C_2, then

$$C_2 = \frac{E}{R_1 + r_1 + G + P} = \frac{x}{R_2 + r_2 + G + Q},$$

therefore $$E(R_2 + r_2 + G) + EQ = x(R_1 + r_1 + G) + xP. \quad (2).$$

…cting equation (1) from (2) we get

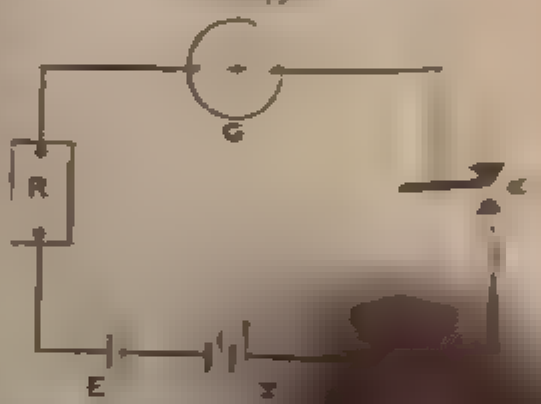
$$E\,Q = x\,P,$$

…fore $$x = E\,\frac{Q}{P}.$$

To ensure accurate results it is essential that the galvanometer [illegible] this test should be sufficiently sensitive to [illegible] …ation in the current strength, and, if [illegible] Q should be as high as or even higher than the [illegible] in the circuit prior to their insertion.

There is another good method which is sometimes very con-[illegible] …nt because it is not necessary to know or ascertain the resist-…ance of any portion of the apparatus, whether it be the …nometer, the rheostat, or the battery, these being the [illegible] …ces required for the test. As in the previous test [illegible] the E.M.F. of the standard cell by E, and that of the [illegible] measured by x. The standard cell E and battery x are …ed up in series, so that they assist each other [illegible] …nt through a rheostat or set of resistance [illegible] …ent galvanometer, G (fig. 93), and the resistance adjusted [illegible] …ly high deflection, say, sixty-[illegible] tangent divisions, is obtained. …, on reversing the standard [illegible] (supposing it to be of lower [illegible] than x) so that the two …'s, x and E, are opposed to [illegible] other, the resulting current [illegible] manifestly be due to the dif-…ce between the two E.M.F.s, [illegible] as the total resistance re-[illegible] unaltered, the current and the deflection [illegible] be diminished, say, to twenty-five [illegible] first deflection (sixty-five divisions) [illegible] the second deflection twenty-five [illegible] between the two E.M.F.s [illegible]

FIG. 93.



$$x : E \; [illegible] \; D + [illegible]$$

$$x = E \; [illegible]$$

Inserting the values as above, we get

$$x = 1\cdot079 \times \frac{65 + 25}{65 - 25} = 2\cdot428 \text{ volts nearly.}$$

The object of reversing the battery or cell of lower E.M.F. is to obtain both deflections on the same side of the zero point. Were the battery of higher E.M.F. to be reversed, it would cause the needle to be deflected to the opposite side of the zero, and if the pointer happened to be bent it would cause an incorrect calculation.

If, when joined up in opposition, no deflection is obtained, then the electro motive force of the standard cell will be the same as that of the battery under test, or $E = x$. The only objection to the method is that in the first case the weaker battery, which is usually the standard cell, has a rather strong current flowing through it which may lower its E.M.F., while, when joined in opposition, the current is passing in the opposite direction and will almost certainly cause a slight increase in its E.M.F. In order to eliminate as much as possible this source of error, it is advisable to introduce a 'key' or contact-maker to open and close the circuit at will, as shown in fig. 93. By the skilful manipulation of this key the needle can be brought to rest immediately without a single oscillation, and the deflection then read before any appreciable alteration of the E.M.F. can take place. As a further precaution, the resistance in circuit should be made as high as possible so as to reduce the strength of the current. By such means the objection becomes almost entirely obviated. To admit of high resistance being placed in the circuit, the 320^{ω} coil of the galvanometer should be used unshunted, and the magnet placed rather low down with its north pole pointing northwards, so that it will act in opposition to the earth's magnetism.

That the resistance of batteries and galvanometer need not be known or ascertained is evident from the fact that they form part of the constant total resistance, which is the same in each case and which does not enter into the calculation. This may be shown algebraically, for if we let R indicate the total resistance in circuit (including batteries and galvanometer), C_1 the current in the first

giving deflection D, and C_2, the weaker current, giving ection d, then

$$C_1 = \frac{x + E}{R}, \text{ or } R = \frac{x + E}{C_1},$$

$$C_2 = \frac{x - E}{R}, \text{ or } R = \frac{x - E}{C_2}.$$

efore $\frac{x + E}{C_1} = \frac{x - E}{C_2}$, or, since the currents are proportional e deflections in tangent divisions, $\frac{x + E}{D} = \frac{x - E}{d}$,

nce
$$D x - D E = d x + d E,$$
$$x(D - d) = E(D + d),$$
$$x = E\frac{D + d}{D - d}.$$

It will doubtless be remembered that, if the poles of a battery joined by a short piece of thick wire having practically no resistance, the current flowing through the circuit will depend simply the E.M.F. of the battery and its internal resistance. Now, thick wire coils of the tangent galvanometer which we have ribed are of very low resistance, and may be used for the urement of the current which a battery can give under these itions. Thus, supposing a battery of twenty Daniell cells, g a resistance of 5 ohms per cell, were joined up to send rrent through one of the low ... of the tangent nometer, the current flowin ... 979 = ·2153 of mpere, and the current ... lar ... ld be the same, ...

[illegible]

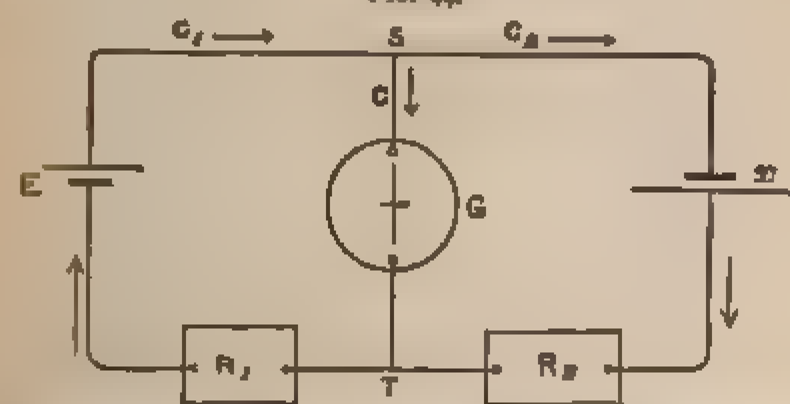
of ten cells gives a current equal to that of the standard cell, it may be fairly concluded that the battery is in good condition, but if a second similar battery gives a deflection of seven or eight degrees less, then the conclusion is that there is something wrong with it; its resistance is too high or its E.M.F. too low. The matter may be quickly decided by joining up the faulty battery in opposition with the similar battery known to be good—that is to say, joining their copper or positive poles together and their zinc or negative poles to the galvanometer. If they then give no deflection, we know that their electro-motive forces are equal, and the fault is proved to be one of high resistance. If, on the other hand, a current is produced, there must be a difference in E.M.F., and the fact that the suspected battery is the faulty one would be demonstrated if the direction of deflection were such as to prove that the other is urging a current through it.

But galvanometers with short thick wire coils having but a few convolutions are only affected by very powerful currents, and are only used where it is essential that the introduction of the instrument into any circuit should have no appreciable effect upon the strength of the current flowing through it. When this restriction is not imposed increased accuracy can usually be obtained by employing a more delicate instrument, in which a coil of many turns, and generally of fine wire offering a high resistance, is employed; because, although the current through the galvanometer is weakened by the added resistance, the effect is more than balanced by the increased number of times which the current travels round the needle. In fact, the flow of a very feeble current through such an instrument, or the maintenance of a very low difference of potential at its terminals, may suffice to produce a good deflection, while under similar conditions a galvanometer with a thick wire coil would be unaffected. It was observed, when considering the Wheatstone bridge method of measuring resistances (Chapter V.), that one great advantage pertaining to it is, that in making the final adjustment only a very weak current or no current at all passes through the galvanometer. It is therefore practicable in such cases to use a very delicate instrument, and, in order to prevent damage being done to the needle or its pivot, or prevent the coils being fused by the passage of a heavy current,

the coil can be shunted until the adjustments are almost completed.

It will also be remembered that the instrument need not be of any particular design, since the final result is obtained with the needle undeflected; a galvanometer such as this can also be employed in several methods which have been devised for the comparison of electro-motive forces, in which the instrument is simply used to denote the *absence* of a current, and in which, therefore, the consequent advantages are the same as in the case of the Wheatstone bridge. Fig. 94 shows the connections for one such method.

FIG. 94.



E is the standard cell and x the battery whose E.M.F. is to be measured. R_1 R_2 are two sets of resistance coils, and G is a delicate galvanometer. A certain resistance is introduced into the circuit by unplugging the necessary coils in R_1, and the resistance in R_2 is adjusted until the current ceases to pass through the galvanometer, thus showing that the two points, S and T, have been brought to the same potential. This being the case, then

$$x : E :: R_2 : R_1,$$

therefore

$$x = E\frac{R_2}{R_1}.$$

As an example, suppose the Latimer Clark cell to be used as a standard, and R_1 fixed at 1,000 ohms, while the potentials at S and T are equalised by making R_2 5,650 ohms, then

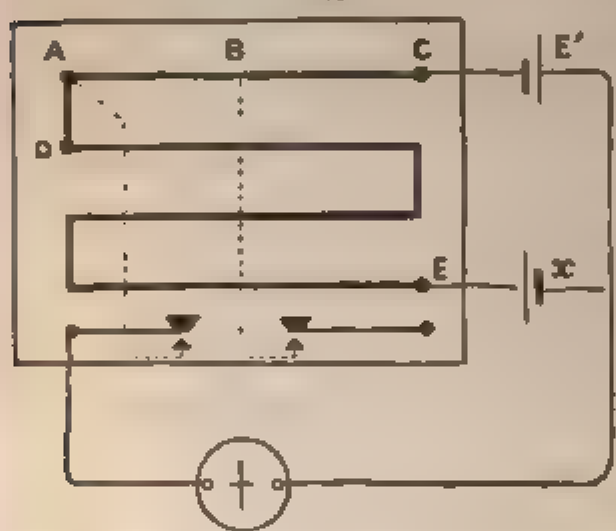
$$x = 1{\cdot}435 \times \frac{5650}{1000} = 1{\cdot}435 \times 5{\cdot}65 = 8{\cdot}108 \text{ volts.}$$

It will be observed that the working out of this example is

simplified on account of R_1 being made 1,000 ohms. For this reason it is preferable to always make the resistance in the same arm as the standard cell some multiple of 10, and obtain a balance by adjusting the other set of coils.

The horizontal galvanometer designed for use with the Wheatstone bridge answers very well for this test, and, as will be seen from fig. 95, the bridge itself may be used for the two sets of coils and then the usual key can be employed in the galvanometer circuit, while the 'infinity' plug between A and D can be used to break the battery circuit and so minimise any error due to polarisation.

Fig. 95.



When a delicate galvanometer is not available, R_1 and R_2 must be lower, but then the battery resistances become important and cannot be ignored. They may, however, be eliminated by increasing one of the resistances, say R_1, by a certain amount, say P ohms, and obtaining a balance again by increasing R_2 by Q ohms. Then

$$x : E :: Q : P,$$

therefore

$$x = E \frac{Q}{P}.$$

The electro-motive forces are, in fact, simply proportional to the increase of the original resistances R_1 and R_2.

For example, if after one balance had been obtained, we were to increase the resistance R_1 by 500 ohms, and again obtain a balance by adding 2,852 ohms to R_2; then $P = 500$ and $Q = 2852$, therefore

$$x = 1{\cdot}435 \times \frac{2852}{500} = 8{\cdot}185 \text{ volts.}$$

The proof of the method depends upon two laws demonstrated by Kirchhoff, which we will endeavour to explain.

Let the resistance R_1 be slightly reduced, so that the balance

is upset, then the currents in the three arms will flow in the direction indicated by the arrows in fig 94.

The first of Kirchhoff's laws (which is almost self-evident in the present simple case), states that the current flowing to the point S is equal to the sum of the currents flowing from it, that is,

$$C_1 = C_2 + C \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).$$

The second law declares that in any complete circuit, even when it forms part of a network, as R_1 E S T, the sum of the products of the current strength in each arm into the resistance of that arm is equal to the sum of all the electro-motive forces in the circuit. That is to say, if in each arm or portion of the circuit the individual resistance of that arm is multiplied by the strength of the current flowing through that resistance, and if all the products so obtained are added together, then the sum so produced will be exactly equal to the sum obtained by adding together all the electro-motive forces in the various arms of the circuit.

The *algebraical* sum must, of course, be taken; for instance, if two currents, or two E.M.F.'s, are opposite in direction, one must be reckoned as *plus* and the other as *minus.*

In the circuit R_1 E S T the only E.M.F. is that of the standard cell, which we denote by E, and, neglecting the internal resistance of this cell, we form the second equation thus:

$$E = C_1 R_1 + C G \quad . \quad . \quad (2).$$

G being the resistance of the galvanometer.

Similarly, in the circuit R_2 x S T, the only E.M.F. is x, but the currents in the two arms are in opposite directions. Therefore

$$x = C_2 R_2 - C G \quad . \quad . \quad . \quad (3).$$

By inserting in (2) the value of C_1, given in (1), we get

$$E = (C_2 + C) R_1 + C G,$$

that is,

$$E = C_2 R_1 + C R_1 + C G \quad . \quad . \quad . \quad . \quad . \quad . \quad (4).$$

From (3), $$C_2 = \frac{C G + x}{R_2};$$

and, inserting this value for C_2 in (4), we get

$$E = \frac{R_1 (C G + x)}{R_2} + C R_1 + C G;$$

$$R_2 E = C R_1 G + R_1 x + C R_1 R_2 + C G R_2;$$

therefore $$C = \frac{R_2 E - R_1 x}{R_1 G + R_1 R_2 + R_2 G} \quad . \quad . \quad . \quad . \quad . \quad (5).$$

This equation gives us the value of the current flowing in the galvanometer circuit when the balance is upset, in terms of the various electro motive forces and resistances. But in making the test we adjust so that no current flows through the galvanometer; therefore, when a balance has been obtained, $C = 0$, and, consequently, the fraction which forms the right-hand side of equation (5) is equal to 0.

Therefore, the numerator of the fraction

$$R_2 E - R_1 x = 0,$$

that is, $$R_2 E = R_1 x, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6).$$

and $$x = E\frac{R_2}{R_1},$$

which proves the case when the battery resistances are so small as to be negligible.

Equation (6) holds good, in fact, so long as R_1 and R_2 represent the total resistance in their respective arms of the system

When the resistances of the batteries cannot be ignored, they must be added to R_1 and R_2 respectively to make up the total resistance in the arm, and then equation (6) becomes

$$E(R_2 + r_2) = x(R_1 + r_1), \quad . \quad . \quad . \quad . \quad . \quad (7).$$

where r_1 is the resistance of the standard cell, and r_2 that of the battery under test. Also, when R_1 is increased by P ohms, and R_2 by Q ohms,

$$E(R_2 + r_2 + Q) = x(R_1 + r_1 + P),$$

that is, $$E(R_2 + r_2) + E\,Q = x(R_1 + r_1) + x\,P \quad . \quad . \quad (8).$$

Subtracting (7) from (8), we obtain

$$E\,Q = x\,P;$$

therefore $$x = E\frac{Q}{P}.$$

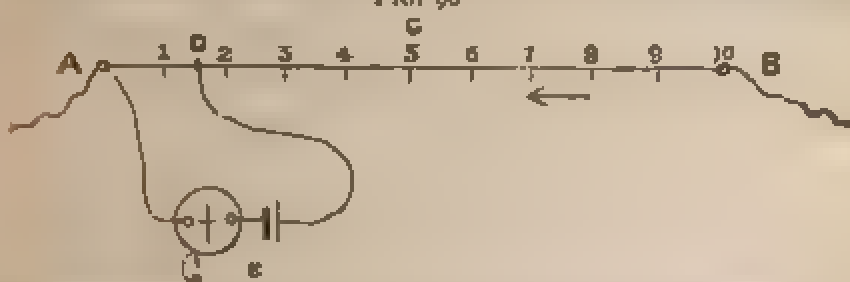
There are a number of very beautiful methods for the comparison of electro-motive forces, somewhat similar in principle to those t described. We have selected a few and worked them out at th, not only because they are in themselves interesting, but

so because they involve, in a rather simple form, some very important principles and laws which the student will do well to master.

We will now direct our attention to a method based upon a somewhat different principle. In this case, again, no current passes through the galvanometer when the final adjustment has been made, thus permitting the use of a delicate instrument. But a further very great point in its favour is the fact that the batteries do not send any current while their E.M.F.'s are being actually compared. Consequently, the Latimer Clark cell may be used as a standard to the best advantage, and the true E.M.F. of a battery subject to polarisation, like the Leclanché, can easily be measured; and further, since no current flows through the batteries or the galvanometer in the battery circuit, their resistances have no effect whatever, and therefore need not be known.

If between the ends A and B (fig. 96) of a uniform German-silver wire one metre (39·37 inches or 1,000 millimetres) in length

Fig. 96



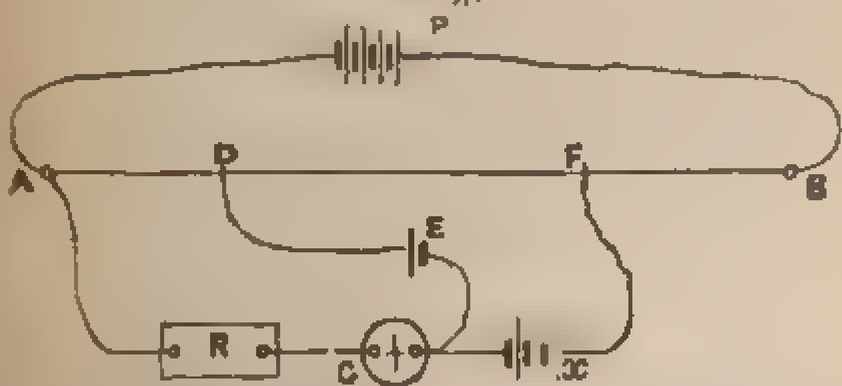
a potential difference of 10 volts is maintained, the fall of potential will be uniform, say, from B to A. Now it must be possible, under such conditions, to find a point in the wire such that the potential difference between that point and the end A shall be any desired fraction of 10 volts. For instance, between A and the middle of the wire, C, the difference is 5 volts. Furthermore, if the negative pole of the Clark standard cell E is joined to the point A, it will assume the same potential as that point, while the end of the wire connected to the positive pole will be 1·435 volts above that potential. A galvanometer may be joined up on either side of E without affecting the final result, and if the free end of the wire is placed to any point near B a current will flow through the galvanometer G in opposition to the standard cell, because the potential of the point near B is more than 1·435 volts above that at A; while,

on the other hand, if contact is made at a point very near to A, where the potential is less than 1·435 volts, the standard cell will be able to maintain a current through the galvanometer and deflect the needle in the direction opposite to that which resulted from making contact at the point near B. Now, between these two positions a point, D, may be found where the needle will be undeflected, showing that no current is passing in either direction through the standard cell and galvanometer, and this point will be such that the difference of potential between it and A is equal to the maximum difference of potential which the standard cell can produce, viz. its E.M.F. of 1·435 volts. Since each of the ten equal parts into which the wire is divided represents a potential difference of one volt, the point D, at which a balance is obtained with the standard cell, should be nearly midway between 1 and 2. If the wire is perfectly uniform in resistance the fall of potential will also be perfectly uniform, and the exact position of the balancing point would then be 143·5 millimetres from A. This shows the advantage of having a wire one metre in length divided into millimetres. As another example, suppose the standard cell were replaced by a battery of unknown E.M.F., we could readily find its E.M.F. by making contact at different points along A B until the absence of a current through the galvanometer indicated that a point had been touched where the E.M.F. is balanced. If this point were 970 millimetres from A, then the E.M.F. of the battery would be 9·7 volts. We have remarked that the resistance of the galvanometer and battery may be high and yet not affect the final result. The only objection to high resistance is that when the balance is nearly, but not quite, obtained, the potential difference tending to send a current through the galvanometer is very small, and if the resistance in the galvanometer circuit is very high the resulting current will be weak and may not be able to affect the galvanometer. This would prevent the balancing point being found exactly, and it is a good plan, in order to avoid such want of sensitiveness, to employ a very delicate galvanometer, and place a set of high resistance coils in circuit with it. At first, all the resistance should be unplugged; it can then be reduced as the adjustment becomes approximately correct, the final adjustment being made with all the resistance out of circuit. Injury to

the galvanometer may thus be avoided, and the greatest possible degree of accuracy attained.

It is clear that if we could with certainty maintain a constant potential difference between the extremities of the graduated wire, no standard cell would be required, and it would be very convenient to be able to measure E.M.F.'s as simply proportional to a certain length of the wire. It is difficult, however, to maintain any given difference of potential between two points for any length of time, and therefore in practice a slightly different arrangement to that just described is adopted. A current is sent through the wire A B (see fig. 97) from some fairly constant generator, P, such

FIG. 97.



as a good low resistance battery or a few of the 'secondary cells' to be described hereafter, sufficient to maintain between A and B a potential difference greater than that of the highest E.M.F. to be measured. The wire is stretched over a scale divided into a thousand parts, and therefore, if of uniform gauge and material, the fall of potential along one of these units is equal to a thousandth part of the fall along the whole wire. The Clark cell, E, and the battery to be measured, *x*, are joined up with their negative poles connected through a galvanometer, G, and a set of coils, R, to the point A, as shown in fig. 97. Their other poles are connected to sliders, by means of which contact may be quickly made with any point along the wire. The whole of the resistance is put in circuit at first, and the slider connected to the standard battery is shifted along until a point is found where the deflection on the galvanometer is very slight when contact is made with the wire A B. The resistance R is then gradually reduced until the exact point (D) is found. The distance from A to D must be carefully noted, and

then a point, F, at which the E.M.F. of the battery x is balanced, is found in a similar manner. Now, the potential difference between A and D is equal to the E.M.F. of the standard cell—that is, 1·435 volts and the potential difference between A and F is equal to the E.M.F. of the battery x. Therefore

$$\text{A D} : \text{A F} :: \text{E} : x.$$

Suppose A D to be 120, and A F 685, divisions; then

$$120 : 685 :: 1{\cdot}435 : x;$$

therefore $$x = \frac{685 \times 1{\cdot}435}{120} = 8{\cdot}19 \text{ volts.}$$

It will thus be seen that it is unnecessary to maintain any particular potential difference per unit of length of the wire, for this can be immediately found by means of the standard cell. But it is advisable, after the adjustments have been made as above, to verify the result by making contact with both sliders at almost the same moment, in order to ascertain whether or not the fall of potential has varied during the test.

In fact, one great feature in favour of this arrangement is that the test may so be made that a slight variation of the potential difference at the ends of the stretched wire need not cause any error; the source of inaccuracy which has most to be guarded against is a want of uniformity in the wire itself. By using a *low* resistance battery a greater proportion of the fall of potential takes place in the external circuit—that is, along the stretched wire—than when a high resistance battery is employed; hence the suitability of secondary cells for this purpose. A greater length of wire may be conveniently obtained by stretching it backwards and forwards several times upon a board. An instrument based upon the foregoing principles for measuring potential differences is commonly called a potentiometer. The wire is sometimes wound in a spiral groove round an ebonite cylinder, and, when made in this form, it can easily be divided into 20,000 parts, but this type is rarely used for practical work.

In all the preceding methods potential difference is measured indirectly or by comparison. Instruments have, however, been devised which indicate directly, in volts, the difference of potential between any two points; such instruments are called voltmeters.

That invented by Major Cardew is very reliable, and it is at the same time simple in principle. If a wire is heated it increases in length. This linear expansion or extension is proportional to the product of the rise in temperature and the coefficient of expansion for the particular wire. The coefficient of linear expansion is defined as the elongation of a body of unit length when its temperature rises from zero to one degree (Centigrade), and this coefficient or proportional extension for platinum is 0·0000088, so that, for an increase in temperature of 10° C., a yard of platinum wire would be extended to 1·000088 yards. By measuring the amount of extension produced by heating a wire, the increased temperature can therefore be inferred. Now, when a current of electricity passes through a wire it performs a certain amount of work in overcoming its resistance, and the generation of heat is the result.

The rise in temperature resulting from the generation of a certain amount of heat does not, however, bear a simple ratio to that amount of heat. It depends, in fact, upon the time or duration of the current and the specific heat or calorific capacity of the particular substance. The former of these factors is so exceedingly apparent that we need not further enlarge upon it. The specific heat of a body is defined as that quantity of heat which it absorbs when its temperature rises through a given range—say from zero to 1° C.—as compared with the quantity of heat which would be absorbed by an equal mass of water when its temperature is exalted through the same range. If, for example, a pound of mercury at 100° C. is mixed with, or placed in, a pound of water at zero, the temperature of the mixture will only be 3° C., so that, while the mercury has lost 97°, the equal mass of water has only increased 3°, or, in simple language, a quantity of water absorbs about thirty-two times as much heat as an equal weight of mercury, in undergoing the same exaltation of temperature. The specific heat of water being taken as unity, that of mercury is therefore 0·03332. Similarly, the specific heat of platinum is 0·03244.

The variation in the temperature of a wire due to an increment or decrement of heat, depends also upon its weight or its sectional area, for it will be evident that if two wires of similar material and of equal resistance, but of different gauge or different weight—

such, for example, as a given length of platinum wire weighing one gramme, and another platinum wire, twice as long, but weighing four grammes (offering, therefore, equal resistances)—have the same current passed through them, they will not be raised to the same temperature, although the amount of heat actually developed will be the same in each case. This follows from the fact that in the one case there is more material to heat than in the other.

When a current of electricity passes through a wire, and performs a certain amount of work in overcoming its resistance, the equivalent of the quantity of energy absorbed in the performance of this work is seen in the development of a definite amount of heat which is imparted to the wire. The heat (H) developed in a unit of time is, in fact, directly proportional to the amount of power expended in overcoming the resistance of the conductor—that is to say, it is proportional to the product of the difference of potential, E, between its extremities, into the strength of the current C, which is maintained through it, or $\text{H} \propto \text{E C}$. If the resistance of the wire remains constant, the value of C varies directly as E; by doubling E, C is also doubled, and the heat developed then varies as the square of E.

Again, the heat unit is defined as that amount of heat which is required to raise 1 gramme of water through 1° C. in temperature, and a potential difference of 1 volt maintained through a resistance of 1 ohm develops 0·24 such heat units per second—that is to say, the number of heat units, H, developed in t seconds, is

$$\text{H} = 0{\cdot}24 \times \text{E C } t.$$

As $\text{E} = \text{C R}$, it follows that $\text{E C} = \text{C}^2 \text{R}$, so that the formula may also be expressed by saying that

$$\text{H} = 0{\cdot}24 \times \text{C}^2 \text{R } t.$$

Collecting all these facts into one simple formula, where T° represents the rise in temperature in Centigrade degrees, E the potential difference in volts, C the current strength in amperes, t the time in seconds, h the specific heat, g the weight of the metal in grammes, and 0·24 the constant which, as pointed out above, is necessary to obtain a result on the Centigrade scale, we may say

$$\text{T}^\circ = 0{\cdot}24 \times \frac{\text{E C } t}{g\,h} = 0{\cdot}24 \times \frac{\text{C}^2\text{R } t}{g\,h};$$

so that a current of one ampere, flowing for one second through a gramme of water (whose specific heat is 1·0), and offering 1 ohm resistance, involving, therefore, a potential difference of 1 volt, would, if all the energy expended were devoted to the generation of heat, be raised 0·24° C. in temperature

Similarly, if the same current were maintained through a platinum wire of the same weight and resistance, the increase of temperature would be

$$T^\circ = 0{\cdot}24 \times \frac{E\,C\,t}{g\,h} = 0{\cdot}24 \times \frac{1 \times 1 \times 1}{1 \times 0{\cdot}03244} = 0{\cdot}24 \times \frac{1}{0{\cdot}03244}$$
$$= 7{\cdot}4^\circ \text{ C., nearly.}$$

In the Cardew voltmeter a length of very fine platinum silver wire is employed, and is heated by the passage of the currents whose E.M.F. it is desired to test. In each test, therefore, g and h retain the same values, and by limiting the increase of temperature to a few degrees, the very slight variation of R becomes a negligible quantity. Similarly, by employing a fine wire, it speedily rises to such a temperature that, with any given current, the loss of heat due to radiation equals in amount that which is developed by the current. The only really variable quantities, therefore, are E and C. But, as already pointed out, C varies uniformly with E, and *if* the facilities for radiation remain the same, the increase of temperature, and with it the elongation, will always be the same for any given value of E. Hence, the amount of elongation can be made to indicate the potential difference maintained between the extremities of the wire.

Simple as the principle is, the construction of a reliable practical instrument is a matter of some difficulty, and an enormous amount of experimental work has been performed in determining the exact sources of error to which a Cardew voltmeter is liable. Fig. 98 illustrates the form of this instrument adopted by Messrs. Goolden after an exhaustive series of experiments extending over a number of years, and in it the inherent sources of variation and error are practically eliminated. The outer casing is removed to show the essential parts as viewed from the back.

The platinum-silver wire is 0·0025 inch ($2\frac{1}{2}$ mils) in diameter, and is fixed at one end to the small brass block *m*. Thence it

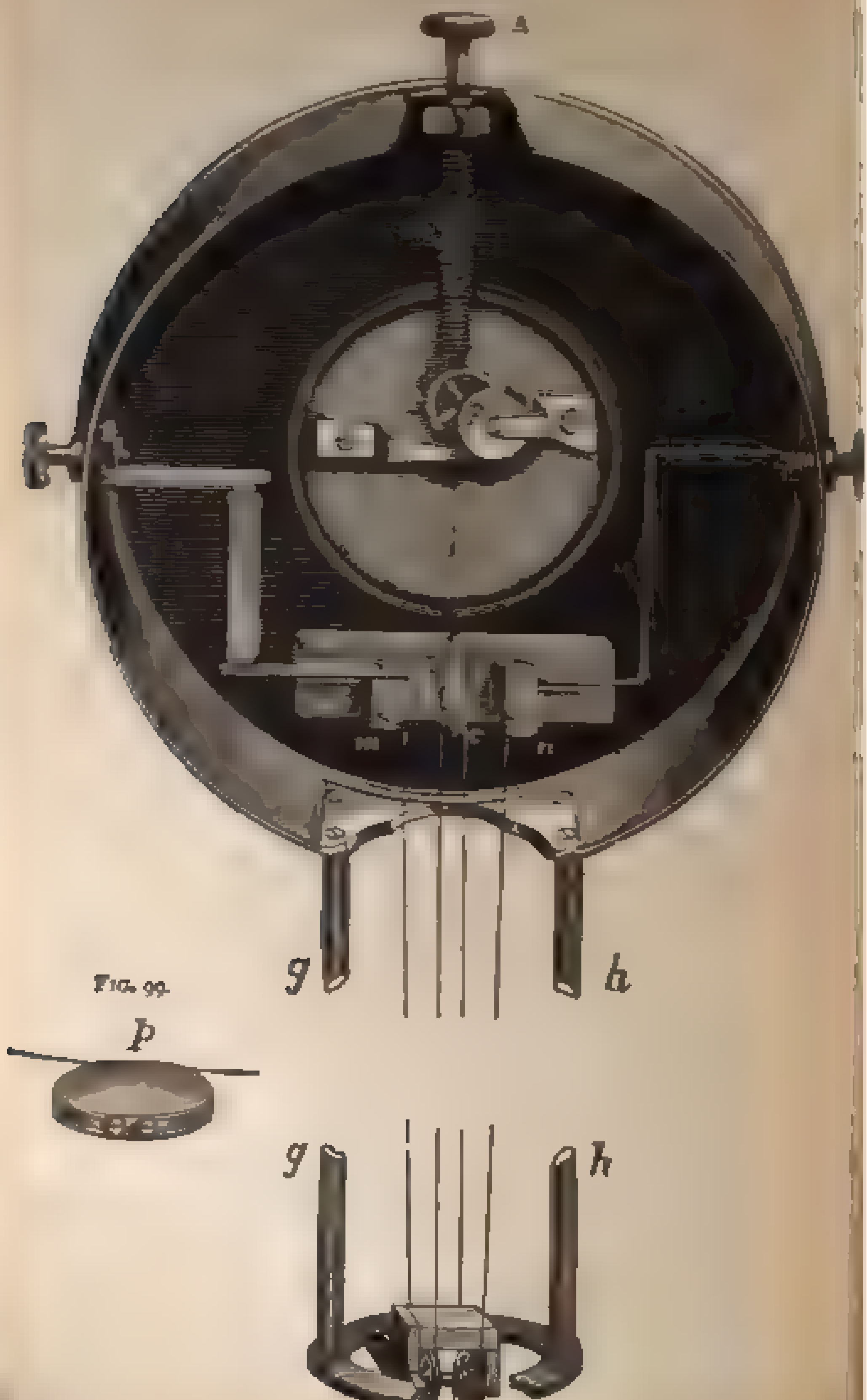


Fig. 99.

is led round one of two grooved pulleys supported by a ring at the ends of two metal rods, *g h*, which are about 36 inches long, and are fixed to the brass base plate. From this pulley the wire returns, and is passed round a small pulley, *c*; thence it is led to the second pulley at the top of the rods, and is finally terminated at the small brass block *n*. The brass pieces *m* and *n* are supported by the insulating block of varnished vulcanised fibre, which is securely fastened to the brass base-plate, and *m* and *n* are connected each to one of the main terminals of the instrument, which are insulated by ebonite or fibre collars from the brass casing. The wire should pass round the pulleys at the top of the rods in such a manner that a pull at *c* on the two centre wires would cause both pulleys to rotate in the same direction, and, the spindle being pivoted in jewelled holes, the friction is reduced to a minimum.

The small part, *c*, referred to as a pulley, only acts as such during the wiring of the instrument, as the extension of the wire when the apparatus is subsequently used does not cause it to rotate. It is made of vulcanised fibre, with a small groove round its circumference in which the wire lies, and is fixed by a small screw passing loosely through its centre to one end of the thin brass strip T, the other end of which has attached to it a fine platinum silver wire, W, connected to the spiral spring S. The tension of this spring, which can be varied by means of the adjusting screw A, keeps the wires taut, and when the main terminals are connected to points in a circuit at different potentials, a current passes—say to the block *m*—up the wire, and round the first pulley back to the insulating reel, *c*; thence, again, to the top of the instrument, round the second pulley, and back by way of *n* to the other terminal. This current heats the wire, which expands, and the slack is immediately taken up by the spiral spring S, so that the small brass strip T and the wire W are moved through a distance equal to the expansion of *two* lengths of the heated wire. The amount of expansion (and therefore of the potential difference applied) is measured by observing the distance through which the length of wire W is moved; but as this distance is, at the most, extremely small, some mechanical multiplying arrangement is necessary, and, since the force producing the movement is also very feeble, great care must be exercised in avoiding the introduc-

and, as the diameter of the wheel is mu
pinion, the pointer is turned through a
tively small extension of the wire

The passing of the wire w round the
able grip, and at the same time avoid fri
the fine wire, is a more difficult matter
appear, and, like every other detail, h
before the method now employed was fi

The pulley is shown separately in fig
parallel grooves round its circumferenc
(where it is filed away flat) two set screw
up home. The wire is led from T roun
screw heads, between which it passes ov
in which it completes its journey round t
to the spiral spring.

The wire is so fine that it would not
the screw heads, but the arrangement d
comes any tendency to slip; and as the
a small angle, never making a complet
friction is introduced. Insignificant as
is, as already indicated, very importan
applies to the shape of the spiral spring
which it is composed. The gradual alte
found to be the main cause of the slight

Although there are four straight lengths of wire equally heated, it will be remembered that the expansion measured is only equal to that of two lengths, for, since *c* does not rotate, its movement would be the same if one of the wires were rigidly fixed to it and the other removed. But it will be noticed that the tension due to the spiral spring is equally distributed between the two wires leading from *c*, and this affords the great advantage that double the tension can be given to the spring, which means that the force with which the pulley *p* is turned can be doubled, and any slight error due to friction correspondingly reduced, without, at the same time, necessitating the adoption of a comparatively thick wire. The wheel work is well made, but it is of course impossible to altogether avoid 'back-lash' that is to say, as the teeth of the driving-wheel do not fit tight between the teeth of the pinion, the latter does not begin to move absolutely at the same moment that the driving-wheel does when its motion is reversed. To avoid the slight error which this might cause, a hair spring is fixed to the pinion spindle. This spring is visible in fig. 98, the pinion being immediately behind and therefore hidden by it. It is adjusted so as to maintain sufficient pressure between the teeth of the wheel and pinion to keep them always in contact, so that in either direction the two move simultaneously.

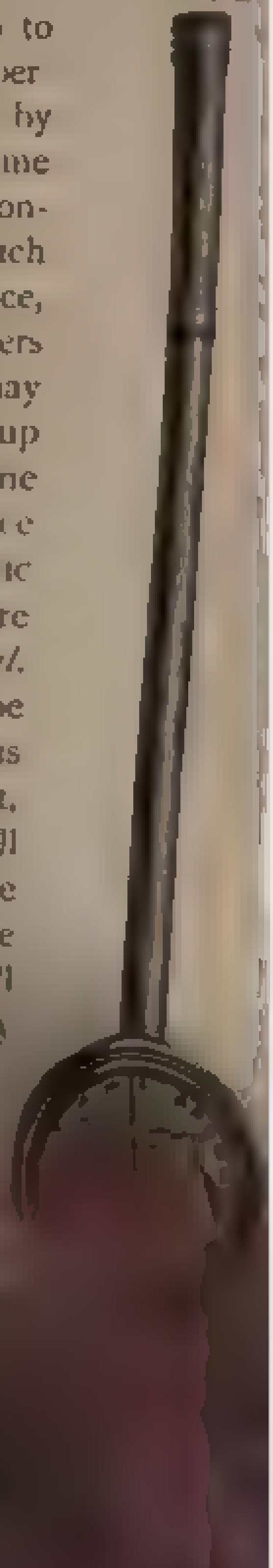
The whole of the casing is of brass, wood, from its liability to warp, being wholly unsuitable; but it is clear that the rods (*g h*, fig. 98) cannot be made of that metal, as, its coefficient of expansion being higher than that of platinum silver, it would expand more than the wire with any rise of temperature, atmospheric or otherwise, and cause a deflection of the pointer. On account of the expense, platinum silver cannot be employed for this purpose. Iron has, however, a lower coefficient of expansion than the wire, and the rods are therefore made partly of iron and partly of brass, the length of these parts being so proportioned that the greater expansion or contraction of the brass shall be neutralised by the lesser expansion or contraction of the iron, and the whole rod vary in length in exactly the same proportion as the wire itself. The wires are encased throughout their length by a brass tube which can easily be removed, and the arrangement of the pulleys, together with an opening in the supporting ring to which they

are attached, facilitates the re-wiring of the instrument. In order to prevent damage to the working wire by the accidental passage of a too powerful current, a safety fuse is inserted in series with it, consisting of a short length of platinum-silver wire, 0·0014 inch ($1\frac{2}{5}$ mils) in diameter, which fuses and breaks the circuit before the current attains sufficient strength to fuse the thicker working wire. This fuse-wire is placed in a slit along the face of a rectangular strip of vulcanised fibre, each end being terminated at a round-headed brass screw in the end of the block, which is firmly held between two flat springs making contact with the screw-heads, one spring being connected to *m* and the other to the left-hand terminal. Several such fuse wire blocks can be kept at hand, and the replacing of a fuse is then but the work of a moment. Connection between *n* and the other terminal is made by a stout, stiff wire.

This type of instrument, in which the wires are supported by the two compound rods, and in which the tube slipped over them simply acts as a casing to protect the wires from air currents and damage, is designed for use with the tube in a vertical position, the end at which the pulleys are fixed being placed uppermost. Now, as soon as the wire gets hot, it heats the adjacent air, which, being displaced by colder air, rises, and consequently currents are set circulating in the tube. The result is that when the pointer is deflected a slight oscillation may be observed, sufficient to prevent the value of the potential difference being read with certainty to within half a volt. This oscillation can be entirely eliminated by simply placing the tube in a horizontal position, for the whole length of the wire then lies in a more evenly heated atmosphere, in which such air currents as rise from it are feebler and more uniform in their distribution in relation to the wire.

A more accurate, though more expensive, instrument is made by dispensing with the rods and fixing the jewelled pulley bearings in the end of the tube itself, which, of course, is then compounded, being made of brass and iron in the necessary proportions. Such instruments are pre-eminently adapted for experimental work, on account of their extreme accuracy, and are, of course, always employed in the horizontal position. The rod pattern (which can also be used horizontally) is, however, a first-rate piece of ap-

for the engine-room or workshop, where a possibl
a volt in the reading is a matter of little moment,
advantage that the working wire can be more
than in the tube form. The voltmeter
d is capable of measuring from 30 to
ts. The calibration is carefully per
the wire being continually heated by
ge of a current, and stretched, for some
viously, to bring it to its normal con-
As it is the heating of the wire which
measure of the electro motive force,
ing error' peculiar to most voltmeters
ntirely absent, and the instrument may
n fact is, kept continually connected up
and weeks together. For the same
e reading is unaffected by the presence
al currents or any electro magnetic
, as iron is not employed and the wire
led, its self-induction is practically *nil.*
lternating potential differences can be
; but it must be remembered that this
nce of self induction in the instrument,
g a current to rise suddenly to its full
its the range through which the fuse
t the working wire for, although the
with certainty if the current rises at all
a very sudden application of a very
. would develop a heavy current in
sly, fuse and wire being melted simul



o is a general view of the Cardew
as made by Messrs. Paterson
e internal portion of the apparatus
from the rear, being shown in
a long piece of
passing up and down the
ported by the tube
her end being attach

[illegible] a small spindle and is kept stretched by means of the wire [illegible] shown in the lower portion of the figure. The wire, therefore, which would otherwise sag or slacken on being heated, is kept taut, acting and reacting with the spring. The spindle round which the thread passes is geared on to the axle carrying the indicating needle which travels over the face of the dial; so that the elongation due to the varying temperature brought about by the different E.M.F.'s can be readily indicated.

Fig. [illegible]

A fine platinum-silver wire fuse is introduced between the brass strips on the left of the figure. The long tube which carries the wire is in two parts, one of brass and the other of iron, so as to allow it to expand equally with the wire under atmospheric changes.

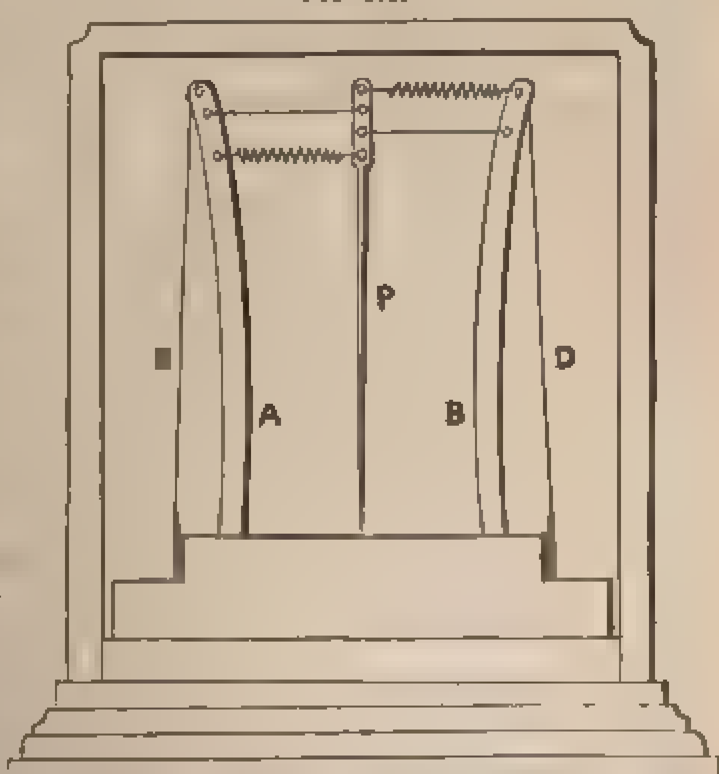
The instruments are usually made to register up to 120 volts, but the values of the readings can very easily be increased by inserting in the circuit, in series, resistance coils of various multiplying powers. Thus, if a coil equal in resistance to the wire in the voltmeter were introduced, it would exactly halve the potential difference of the current at the terminals of the voltmeter due to any particular E.M.F. Manifestly, such a coil would have a multiplying power of two, while a coil of three times the resistance would reduce the proportion of potential difference absorbed by the voltmeter to one fourth, and therefore have a multiplying power of four. These resistance coils, how[illegible] must not be of the ordinary type. The wire should be of [illegible]m silver, of the same gauge as in the voltmeter, and in [illegible]o produce exactly equal facilities for radiation it should be

bare, and, for convenience, it may be stretched over a kind of rectangular framework made by attaching two rods of slate to a couple of strips of wood, notches being made in the slate to receive the wire and prevent one portion slipping into contact with another. The wire and framework are enclosed by pieces of thin sheet iron.

The ordinary Cardew voltmeter, although the best and most useful instrument for the measurement of high voltages, is not available for the estimation of low potential differences, owing to the exceedingly small elongation due to the slight rise in temperature, and the consequent vagueness of the reading which would result therefrom.

Recognising the necessity for the production of an instrument capable of measuring low E.M.F.'s more particularly for testing the voltage of secondary cells - Major Cardew has just designed one, the working parts being shown in fig. 102. The range is from 0·5 to 2·5 volts, the scale, as shown in fig. 103, being divided into tenths of a volt.

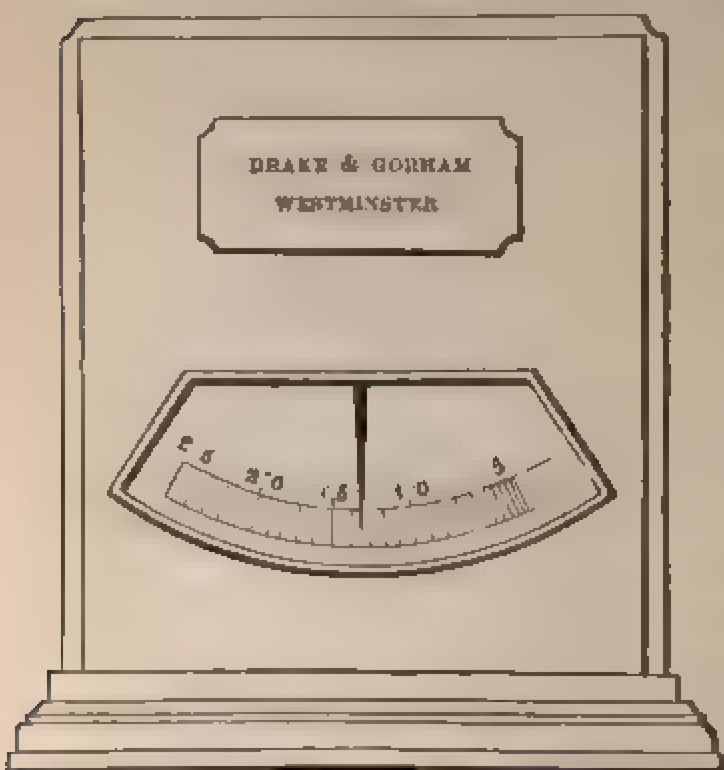
Fig. 102.



Two pieces of platinum-silver wire, C and D (fig. 102), are kept taut by means of the upright bows, A B. The indicating needle P is supported and held in position by two horizontal pieces of wire and a couple of spiral springs. The lower ends of the wires C D are connected to terminals on the case of the instrument, so that when a current passes through the instrument it travels up one wire and across, by way of the thicker part of the needle, to the other wire This current raises the temperature of the wires C and D, which, by their consequent ex-

tension, allow the upper ends of the bows to approach each other. This motion is transmitted by means of the stiff horizontal wires to the needle, which therefore travels over the scale from right to left. In the figures the needle is shown over the centre of the scale as if deflected by the application of an E.M.F of 1·33 volts. It will be observed that there is absolutely no friction—a most important feature, which, as a matter of fact, renders the instrument a possibility. It is also an inexpensive piece of apparatus.

Fig. 103.

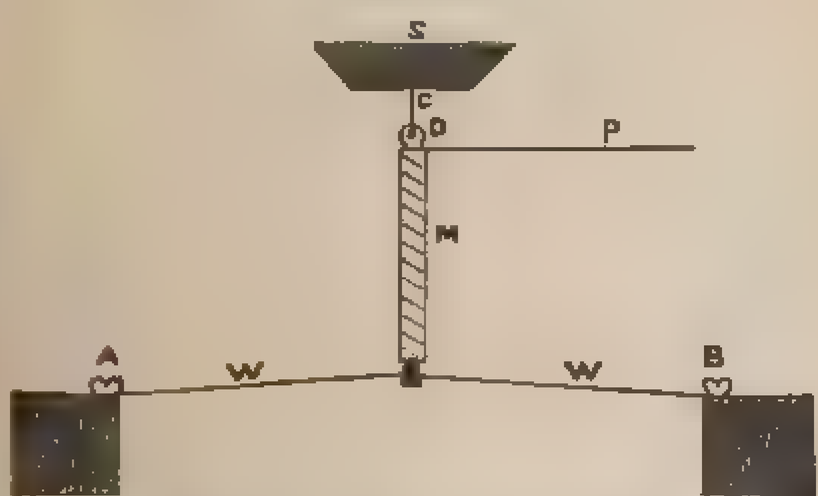


Professors Ayrton and Perry have introduced another, but somewhat more complicated, modification of the Cardew voltmeter, which is capable of accurately measuring low potential differences, and indicating small fractions of a volt. The principle upon which this apparatus is constructed will be easily understood by a reference to the diagram, fig. 104. W W is a short piece of platinum-silver wire, 0·0014 inch in diameter. The ends of this wire are held rigidly by the terminal screws A and B. The centre of the wire rests in a stirrup supported by the magnifying spring M, which is similar to that illustrated in fig. 61. The upper end of the spring carries a pointer P, and is kept in position by a piece of fine wire, C D, fixed, at its upper extremity, to the support S. On a comparatively feeble current—that is to say a current caused by a small difference of potential—passing through the wire W, it is elongated and the sag is increased. The tension on the spring is thereby reduced, and, the lower end being fixed, the upper end revolves and carries the pointer with it. The pointer

oves over a dial, and indicates directly the amount of coiling to hich the spring is subjected by the sag on the wire. So sensitive this arrangement that when the initial sag on the wire is comratively small—that is to say, when the wire is stretched almost a straight line between the terminals –sufficient change in the g results from the application of a potential difference of eight ten volts at the extremities of a wire eight inches long, to proce, when magnified by the spring, a complete rotation of the ointer.

If, in a voltmeter of this kind, the wire is further shortened,

FIG. 104.

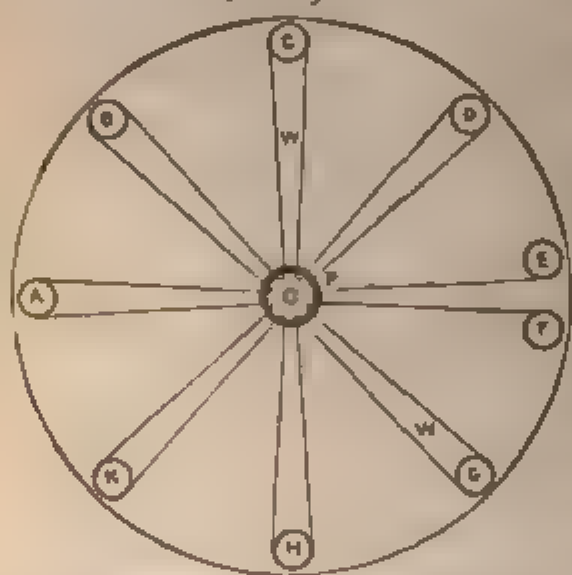


he instrument will indicate a still lower potential difference, cause the shortening decreases the resistance, and so augments e current resulting from a given potential difference, and also ecause, the mass of the wire being reduced, its temperature rises gher with a given quantity of heat. But the wire cannot be ortened indefinitely, as it is so fine that the temperature beyond hich it is unsafe to work is quickly reached. It is, however, ossible to obtain the first-mentioned effect without the second. or instance, in the case of what may be called the bicycle-wheel rm of instrument (fig. 105), the whole of the wires can be joined series, or grouped variously in parallel. In the latter case, the esistance being much decreased, the stronger current develops a eater amount of heat in the spokes, thus affording a means y which an instrument may be used for much lower potential fferences than it can be with the spokes in series. The mass

of metal affected by the heat is, however, the same in t
case.

The design of this form of the instrument is ingenious. Ro
a ring of metal a number of non-conducting studs, A B C, &c
fixed. There is also a small non-conducting central piece,
which a magnifying spri
attached, at right angles t
plane of the ring. One
of the wire is attached t
stud E, and passes to an
between the hub or c
piece P and the various
the other end being fi
the stud F. This dev
the advantage that ev
tion of the wire is affe
the current, so that the
need to introduce re
coils into the external

Fig. 105.



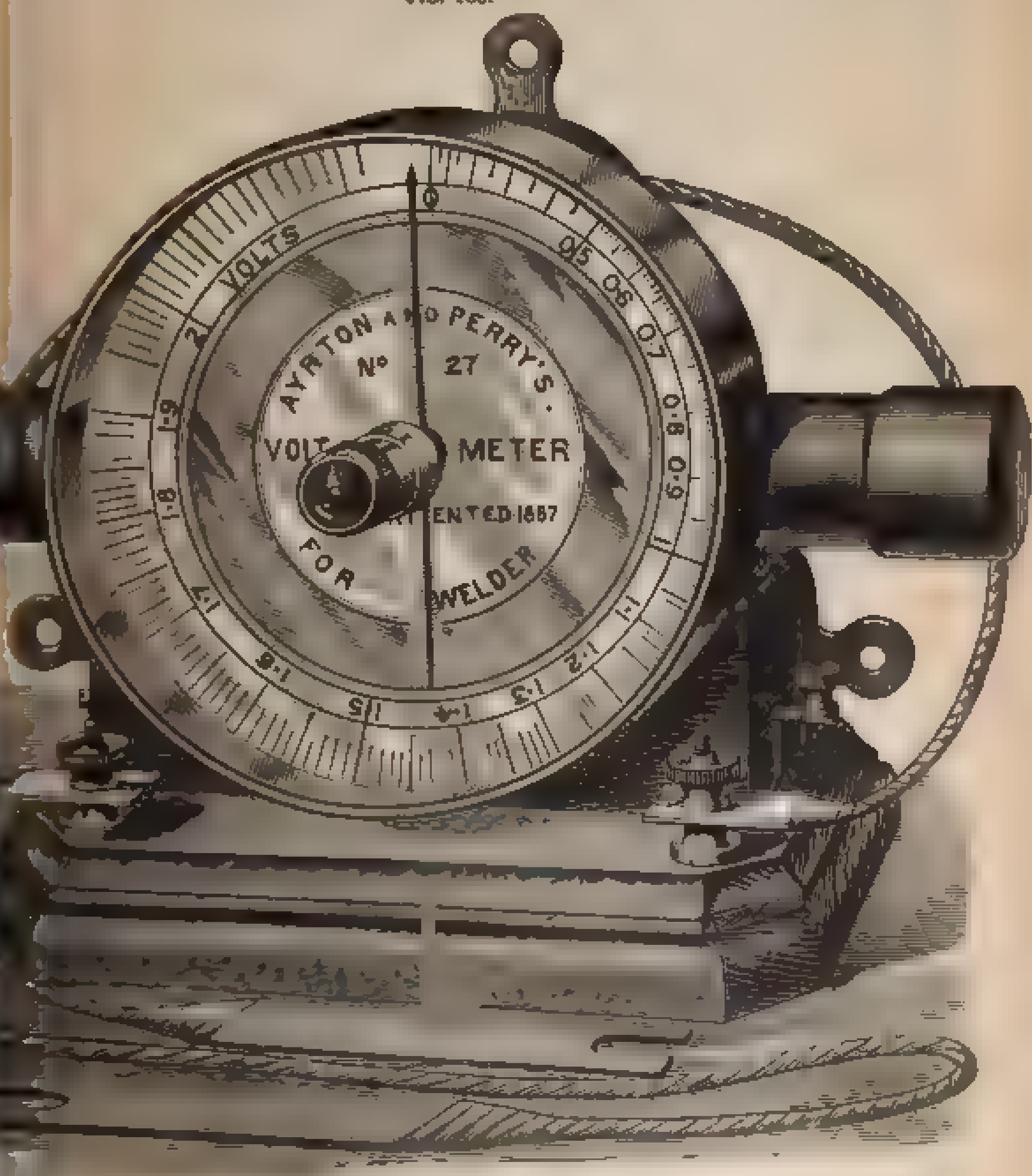
to indicate the higher voltages, all that is necessary b
already indicated, to join the 'spokes' in series.

Fig. 106 is a general view of one of these hot wire vo
constructed to measure the alternating potential differen
terminals of a coil used in electrical welding, which ranges
1 and 2 volts. The scale is 6 inches in diameter and div
hundredths of a volt.

In the original instruments, the principle of which is il
in fig. 104, the pull of the magnifying spring M was counte
by the pull of the platinum silver wire W W attached to
minal blocks; but in the recent form, of which fig. 107 i
zontal section, both these pulls act, in order to economi
in the same direction, and are counterbalanced by the flat
Hence, as the wire stretches, the magnifying spring M is s
and the pointer P (provided with a number of fine hairs fo
ing without any great inertia) rotates in front of the di
flat spring S has therefore the effect of reducing the dime
the instrument, and it also allows of the adoption of
arrangement for a fuse, to protect the wire from an ov

ment. In the ordinary Cardew voltmeter, with a wire two yards length, the introduction of a short fuse which will melt with a ment just too small to damage the instrument does not seriously ease the resistance or diminish the sensibility; but in this

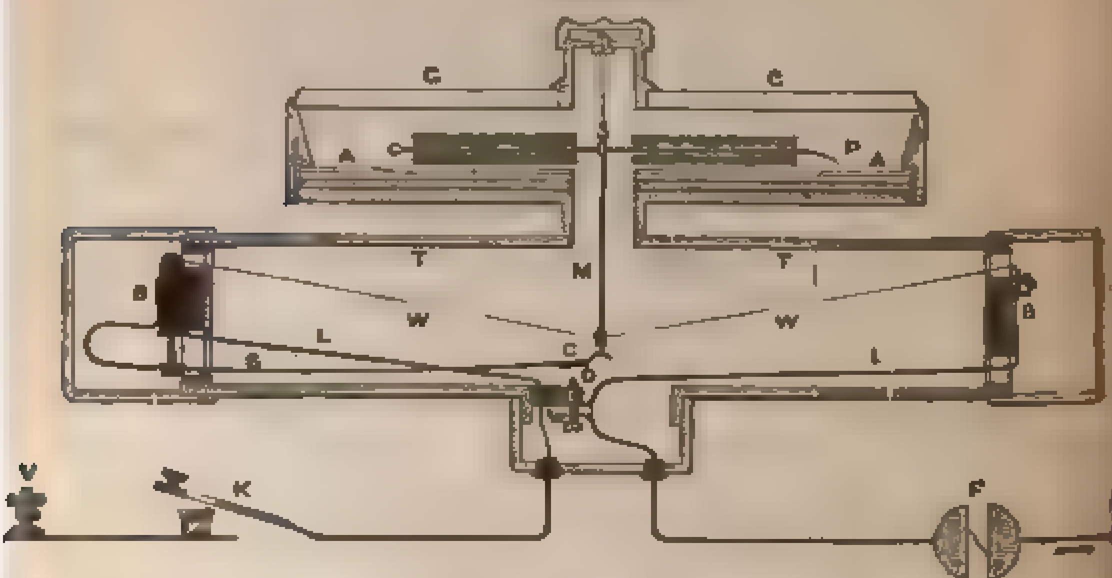
FIG. 106.



dification, which sometimes contains only 8 inches of wire, the oduction of such a fuse would considerably diminish the sensi-ity, and it is practically impossible to diminish the length of the

fuse in proportion to the length of the working wire, in consequence of the fact that the metallic blocks to which the fuse wire would have to be attached would conduct the heat away so rapidly as to prevent an extremely short piece of wire from melting. To overcome this difficulty a fuse, F, is employed, of such a diameter that it would require a far larger current to melt it than would suffice to damage the instrument. A small platinum tipped screw D, electrically connected with the wire L, passes through a small insulating block, so that when the wire W W stretches by any prearranged percentage beyond the amount it stretches for the maximum safe potential difference, the platinum contact C on the flat

Fig. 10[illegible].



spring S makes contact with the screw D, and the working wire is consequently short-circuited. The circuit is then temporarily completed through the screw D, a portion of the wire L, and the fuse F, when the current proportionally increases and the fuse is melted without any risk of damage to the instrument. It follows that by this arrangement a thick fuse-wire can be employed, offering but a small resistance compared with that of the working wire, while the sudden application of a potential difference five or six times as great as the maximum potential difference the voltmeter is intended to measure, melts the fuse readily. The fuse F, key K, and terminals V V are shown, for simplicity sake, detached from the instrument, their actual position being, of course, on the base

[redacted]

t may be added [illegible]
nds in a great [illegible]
great care is therefore [illegible]

Ve come now to a consideration [illegible]
ert the instruments which we [illegible]
able for the measurement of [illegible]
d ammeters, so that they [illegible]
An ammeter measures [illegible]
ng through its coils, and this current [illegible]
ence of potential at the terminals [illegible]
t, therefore, at first sight appear [illegible]
to measure the potential [illegible]
mply joining it up to them [illegible]
flowing, and from that inferring the [illegible]
n maintains it. But the very act of [illegible]
uit by the low resistance ammeter [illegible]
e potential difference considerably [illegible]
ure the potential difference [illegible]
y portion of a circuit is usually applied [illegible]
onsequently, although the ammeter [illegible]
ate the potential difference between [illegible]
so joined, it would give no information [illegible]
e. For instance, if a piece of German-silver [illegible]
istance of 5 ohms, forms part of a [illegible]
nt of 4 amperes is flowing, we know that the [illegible]
ntial between its terminals is $4 \times 5 = 20$ [illegible]
f we proceed to measure these volts, by connecting an
eter having a fraction of an ohm resistance to the ends of the
we shall get much less than 20 volts, for the resistance and
fore the fall of potential, in that portion of the circuit will
been considerably lowered. Although the total current in the
circuit will be increased by this lowering of the total re
the ammeter resistance is so low that it shunts the
of the current from the German-silver wire; and su
in consequence, only half an ampere flows through
otential difference at its ends will be $C \times R = \cdot 5 \times 5 =$
instead of 20.

In order that the introduction of the instrument should make absolutely no alteration, no current at all should flow through it; and although there are instruments which satisfy this condition the majority are only suitable for use in the laboratory. If, however, we take any ordinary ammeter and wind it with a large number of turns of fine wire, so that it has a very high resistance, it can be used as a voltmeter; for its resistance will be too great, and the current which passes through it will be too small, to make any sensible alteration in the potential difference which is measuring; while, on the other hand, the large number of turns of wire will allow the feeble current so flowing to produce a sufficient strong magnetic field to actuate the movable part of the apparatus. For instance, one of the ammeters, described in Chapter IV, when wound with fine wire to a resistance of about 2,000 ohms will serve to measure potential differences of from 60 to 120 volts. Of course, it can and must be 'calibrated' for reading in volts in the same way that the ammeter was calibrated for reading amperes.

One important source of error must, however, be guarded against; it is due to the fact that a current, in passing through the coils of a voltmeter, heats the wire and increases its resistance, and consequently a given difference of potential will send a weaker current through the coils after they are heated than before. The instrument will therefore indicate a lower difference of potential than that which actually exists, in consequence of the fact that it measures the potential difference by the strength of the current set up by that difference. For this reason great care must be exercised to prevent the coils of a voltmeter being heated to an appreciable extent by the current, and in order to secure this condition a key should always be supplied with such an instrument. The reading can then be taken immediately the circuit through the coils is completed by the depression of the key, and before the resistance rises. In the case of an ammeter the resistance of the coils is so very low that but little heat is generated there, and, the size of the wire being comparatively great, the temperature, and therefore the resistance, varies but slightly. Further, an ammeter is not used as a shunt, but is placed directly in the circuit, it is virtually free from this 'heating error,' because, u

l circumstances, the strength of the current flowing through it d measured by it is the same as that in the rest of the circuit.

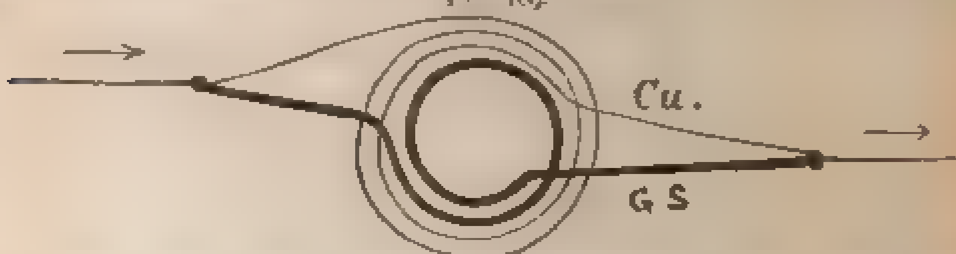
The Shuckert, the Steelyard, and the Eccentric-iron-disc mmeters, and many others of a similar character which we have ot described, can be converted into voltmeters by the simple bstitution of a long-wire coil of high resistance for the short-wire oil of low resistance, and this, apart from the calibration, being e only essential difference between these types of instruments, ere is no need to further enlarge upon them. An exception ay perhaps be made in the case of Evershed's Gravity voltmeter, general view of which is given in fig. 108. Its moving parts are actly similar to those of the Gravity mmeter shown in fig. 67, but, of urse, thin wire, offering high resist- nce, is employed. Only a portion this wire forms the actual magnet- ing coil, this being of copper, while e remainder, which is of German lver, is wound round a large metallic linder inside the casing. In an strument indicating up to 110 volts e total resistance would be rather er 2,000 ohms, that of the actual agnetising coil being about 200 ohms, so that, with the maximum otential difference, the power absorbed is only 6 watts; and, as e temperature coefficient of German silver is low, as also e disposition of the wire gives fairly good facilities for radiation, s temperature does not rise appreciably. Consequently, the strument may be left continually on the circuit without causing ny error worth noticing under ordinary working conditions.

Fig. 108.

For cases where it is imperative that the indications should be ntirely free from heating error, Mr. Evershed has suggested a very genious method of compensating which may be applied to this r any similar voltmeter. It is based upon the observed fact that e temperature coefficients of metals are different—that is to say, given rise of temperature causes a greater increase per cent. in e resistance of some metals than of others, the difference in certain ases, such as copper and German silver, being considerable. The

magnetising coil proper consists of German silver wire, and a higher resistance coil of copper wire is wound round it in the reverse direction, as indicated in fig. 109, the two being connected in parallel, so that the copper coil not only forms a shunt to, but opposes the magnetic effect of the other coil, the resultant force acting on the needle being due to the excess of the magnetic effect of the German silver over that of the copper coil. The wire of the latter is made very thin, to enable the necessary resistance to be obtained while keeping the ampere turns sufficiently low, the number of ampere-turns in the German silver coil being several times greater than in the copper. When the current or atmo-

FIG. 109.



spheric changes cause a rise in temperature, and therefore also in resistance, the current in the German-silver coil decreases slightly, but that in the copper coil decreases in a much faster ratio, because the temperature coefficient of copper is so much greater; and if the resistances and diameters of the two wires are made such that the current in the copper coil decreases just fast enough to keep the difference between the magnetic effects of the two coils constant, the instrument will compensate itself for any variation in temperature. Unfortunately, the calculations required are somewhat difficult, and the copper wire must be extremely thin, so that this extremely ingenious method has not yet made much headway.

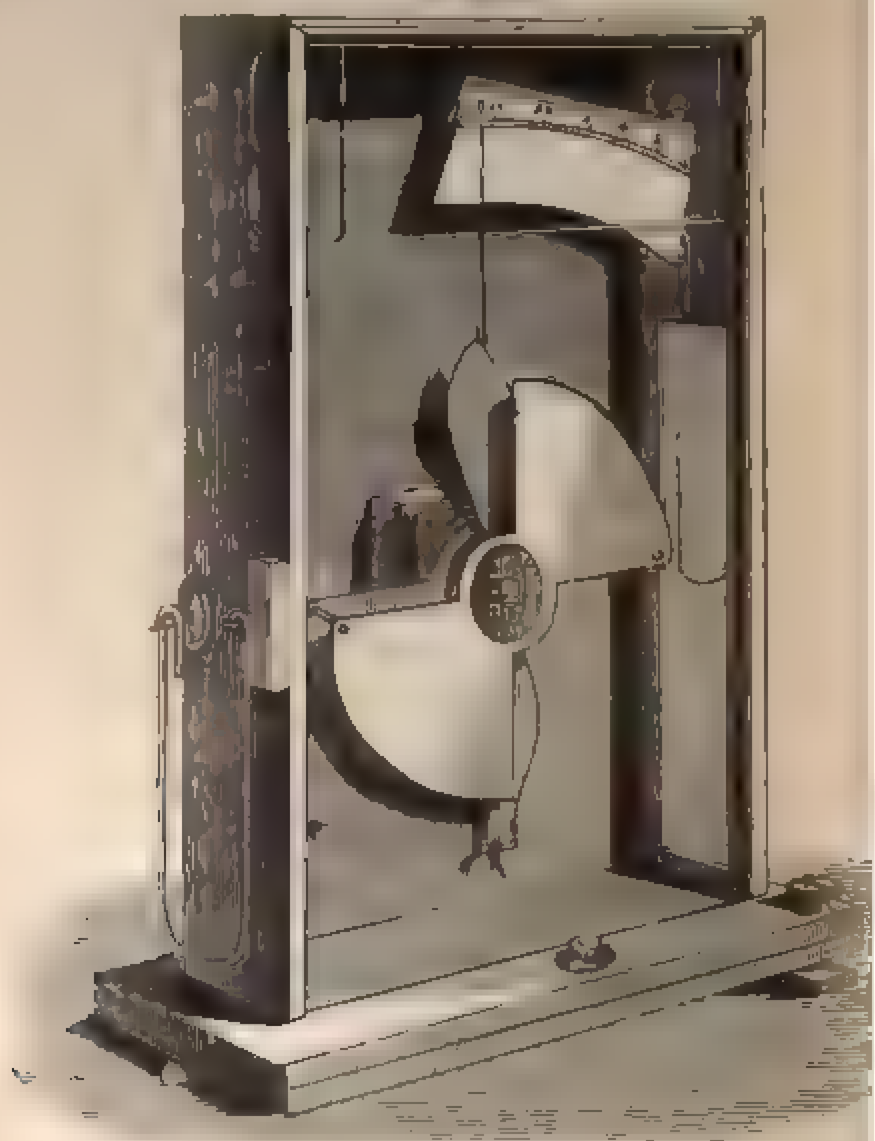
In the recent development of electric lighting the tendency is towards the use of very great differences of potential, much greater than any we have hitherto dealt with. In one case, for instance, it is proposed to work at a potential difference of 10,000 volts. This potential difference is alternating, thus excluding at once a ...re number of measuring instruments; and it will readily be ...eived that those which we have described as capable of ...uring alternating potential differences could not well be

odified so as to measure up to 10,000 volts. A voltmeter has en introduced by Sir William Thomson, based upon the well-own elementary fact that two adjacent bodies at different poten-s mutually attract each other. We have seen that a simple y of establishing this difference of potential is to rub two dis-milar substances, such as a piece of flannel and a piece of sealing-x, together; they will then mutually attract each other, and force of this attraction might serve to estimate the potential ference between them. But there is a difference of potential tween the two poles of a battery; if these two poles are con-cted one to each of two insulated metal conductors (say brass heres), the spheres will be at different potentials and will attract ch other, the force of attraction is, however, too feeble to cause y perceptible movement, unless very delicate refinements, un-itable for workshop use, are resorted to. But for this latter t, such a method of measuring potential difference would be fect in one respect, for, as the two conductors are insulated, no rrent whatever would flow from the battery, and we might there-e measure the potential difference without altering it during act of measurement. The use of this 'electrostatic' method, wever, becomes practicable in the case of several hundred ts, and fig. 110 shows Sir William Thomson's voltmeter, which based upon it.

One conductor is fixed and the other movable; the fixed one sists of two butterfly-shaped sheets of brass, parallel to each er, and metallically connected, but carefully insulated from the of the instrument. The movable conductor is a thin alu-nium strip, supported at its centre on a knife edge, and moving ely in a vertical plane exactly midway between the two fixed ss plates. When at rest the movable plate or strip is kept in a tical position by very small weights placed on a knife-edge at lower extremity. If a difference of potential is established ween the fixed plates and the movable strip, mutual attraction ults, and the aluminium tends to set itself in a position, as far possible, inside the fixed plates, this tendency being counter-ed by the weights which it carries. The force of attraction is portional to the square of the potential difference, the movable ductor, of course, comes to rest when the forces due to the

electrostatic attraction and to gravity balance, and this p
rest is indicated by a light pointer moving over a gradua
This scale has 60 divisions, which represent equal diffe
potential, and a large range is obtained by varying the
weights. When a weight of 32·5 milligrammes is used, th

FIG. [illegible]



moves through one division for a potential difference of
with 130 milligrammes one division corresponds to 100 v
with 520 milligrammes to 200 volts But with 10,000
upwards there is danger of sparking between the plate
particular instrument, it is, however, possible to increase
tance between them, and then to measure much highe

arc.[3]

CHAPTER VII.

ELECTRO-MAGNETS—ELECTRO MAGNETIC INDUCTIO

It has been observed that the air space in the neighbou a wire, in which the effect of a current travelling in th perceptible, is called an electro magnetic field, and that th tion in which the force in this field acts can be made ev means of iron filings, which, if sprinkled upon a sheet with the wire passing through it, arrange themselves in co circles along the lines of force round the wire. And fu will be remembered that some substances offer greater than others for the propagation of these lines of force, an is possible to alter their circular form by bringing near the substance through which they pass with either more or l than through the air. The relative capability possessed by stance for conducting these lines of force is known as its ability,' and it is obviously desirable that some method of d comparing this property in various bodies should be adopt permeability of air[1] can be taken as the standard, and meability of all other substances measured by comparison

If a piece of hard steel is placed in any magnetic fiel of the adjacent lines of force are bent out of their previou and converge into the steel. More lines of force, theref through the space occupied by the steel than passed thro same space when occupied by air alone. Hence we c that the lines of force pass through steel more readily than air, or the permeability of steel is greater than that of again, the steel is replaced by a piece of soft iron of simil and size, even more lines of force will now pass through t

[1] The permeability of a vacuum is taken as unity; that of air is alm the same, and is a more convenient standard.

ce, showing that the permeability of soft iron is still greater
s that of steel. In fact, the permeability of any substance
ht be measured by dividing the number of lines of force which
s through it, by the number which pass through the same space
n the substance is removed, the strength of the magnetising
l being the same in both cases. There is, however, no method
ilable for determining the actual number of lines of force per-
ing any particular space or substance. The nearest approach
uch a desideratum would be to measure the relative strength
ny electro-magnetic field, or of any given portion of it, because,
night be supposed, the strength of the field varies directly as
number of lines of force pervading it. But here again we are
et with practical difficulties, for, except in comparatively simple
s, even this is not ascertainable directly, and can only be
luced from other effects.

It is, however, possible to compare the strength of fields by
asuring the magnitude of various phenomena which can be
de to take place in them ; one such method is briefly described
the end of this chapter.

We can thus measure the strength of a field due to any mag-
ising force—that is, the number of lines of force passing
ough any given air space—and then, filling that same space
h a piece of iron, measure the relative number then passing
ough the iron. The number of lines of force passing through
area of one square centimetre taken at right angles to them is
led the amount of magnetic induction ; the [illegible]
ough the air space is equal to the strength of the [illegible]
e permeability of air is 1), and the magnetic [illegible]
e iron, divided by the strength of the magnetising field [illegible]
meability of the iron.

By experimenting in this way it has been proved beyond doubt
t not only do different substances possess various degrees
meability, but also that this property may vary considerabl
ne substance under certain conditions ; and it is also
arrange the various substances in the order of their
of permeability. The most permeable material kn
ft iron, and it is found that, generally speaking,
nd impurity of the iron increase, so its perm

decreases; that of hard steel, nickel and manganese being comparatively low. The vast majority of substances, including most of the other metals, are very nearly equal to air in this respect, while the permeability of a few metals, including bismuth and copper, is less than that of air. To take the two extreme cases, the permeability of iron has been known to reach as high as 19,000—that is to say, 19,000 times as many lines of force have been known to pass through a certain piece of iron than passed through the equivalent air space when the iron was absent, while that of bismuth has not been found to be much below 0·99998.

This property is very important in some practical operations, and (especially in the case of iron) it is useful to know the conditions under which it varies in the same material. We have already touched upon a practical application in the case of a helix or solenoid, and are now in a position to further consider the matter. We observed that the electro magnetic effect of a helix carrying a current can be increased in two ways—either by increasing the strength of the current and so increasing the actual number of lines of force produced, whatever that number may be, or by increasing the effect of the available lines of force by making as many of them as possible pass through that space near the ends, where they will be able to act to the greatest advantage. The permeability of bismuth and copper being less than that of air, either of these substances, when placed in an electro-magnetic field, will *decrease* the number of lines of force passing through the space which it occupies; but even in the case of the most effective substance known, viz. bismuth, the difference is so very slight that it is difficult to perceive or measure it. If, however, any substance were to be discovered with a permeability very much less than that of air, one way of leading the lines of force through the desired space would be to place this substance in that part of the field from which it is wished to exclude those lines—that is to say, to make all paths but the right one, or the one desired, as difficult as possible. But the permeability even of bismuth being so little inferior to that of air, the only available method of attaining the desired end is to make the path which it is desired the lines of force should take as easy as possible. In the case of the solenoid described in Chapter IV. we wished to increase its effect

by leading as many as possible of the lines of force through the ends of the coil, instead of allowing them to leak out at the sides, and for this purpose fitted it with a soft iron core, which had the desired effect. Since the permeability of different qualities of iron varies so much, too great care cannot be exercised in its selection; and, experiment having shown that soft annealed Swedish iron is superior to all other kinds, this should, when the question of expense does not forbid, be used in all cases where it is desired to concentrate the lines of force at any particular point.

It will be remembered that a helix of wire fitted with an iron core is called an electro-magnet, and electro-magnets differ in shape and arrangement according to the work they are intended to perform. Thus, if it were wished with one pole of an electro-magnet to repel a similar pole of another electro-magnet, or of a permanent steel magnet, with as much force as possible, it should be made long and straight, so that its opposite pole might be as far away as possible. It frequently happens, however, that an electro-magnet is required either to support a heavy weight or to attract another magnet or a piece of iron as powerfully as possible. It is then more advantageous to allow both poles of the electro magnet to act together, and this can be accomplished by making it somewhat similar in shape to a horse-shoe, and so bringing the poles close together, as is the case in fig. 111, winding the wire only over the 'legs' of the iron core.

Fig. 111.

In designing an electro magnet, therefore, the object to which it is intended to apply the apparatus must be kept clearly in view, and it is necessary that the general principles underlying the science of electro magnetic construction should be now considered, although, under the most favourable circumstances, these laws and principles are somewhat complicated and involved, and, to a great extent, indeterminate.

In the generation of an electro magnetic field by means of a solenoid there are two prime features to be taken into considera-

tion—viz. the strength of the current and the number of convolutions of wire constituting the coil. It can readily be seen that the electro-magnetic effect produced by a current varies directly as the strength of that current, so that to double the intensity of the field developed by any particular coil it will suffice to double the current strength. There is, therefore, no need to take into account the resistance of the wire, except in so far as it may modify the current strength, the resistance varying, of course, directly as the length, and inversely as the square of the diameter, of the wire.

As the current strength in any circuit is the same in all parts, or at all points, of that circuit, the electro-magnetic field developed by any unit length—say one inch of the wire—is exactly equal to that developed by any other portion of the circuit of equal length. It follows, therefore, that two convolutions or turns of wire close together will generate a field twice as strong as that which can be developed by either of the turns taken separately; and, speaking generally, it can be said that the field developed by a solenoid varies in strength, directly as the number of convolutions. And this will be true whatever the nature of the material forming the conductor, or whatever its resistance. Nor does the diameter of the circle described by the wire when coiled into a long helix materially affect the strength of the field developed at its centre, unless the diameter exceeds about one half the length of the coil. The dimensions of the iron forming the core have also to be taken into account, but that topic will be considered presently.

Placing these two factors together, then, the field developed by an electro magnet can be said to vary directly as the current strength, and directly as the number of convolutions of wire, or

$$M \propto Cn,$$

where M is the strength of the field, C the strength of the current, and n the number of turns.

Since C is measured in amperes, this simple formula is frequently expressed by saying that the field varies as, or is equal to, the 'ampere turns.' As the number of lines of force is proportional to the length of the wire and the current flowing through it, it would be more correct to speak of the magnetic effect as being proportional to the ampere feet or ampere-yards; but as

to ampere-turns is generally adopted, we also make use

stated just now that the diameter of the coil was, with a reservation, immaterial; but it must be remembered that, ng the number of cells in the battery to be a fixed quantity, ease or decrease in the diameter of the coil must proportion- rease or decrease the length of the wire and its resistance, se thereby a decrease or increase in the current strength, this variation in the length of wire is accompanied by a onding variation in its cross-section, so as to keep the re- constant. The all important Ohm's law must always be ll in view in making any changes of this sort, or serious ies will arise. Let us suppose that a wire offering 5 ohms ce is coiled into a solenoid composed of, say, 10 turns, ming one single layer, and that a current from 5 cells of electro-motive force and 1 ohm resistance per cell passes the coil. The current strength, supposing the connecting be short and thick, and to have therefore no appreciable ce, will be

$$c = \frac{10}{5+5} = 1 \text{ ampere},$$

field will be proportional to

$$c \times n = 1 \times 10 = 10.$$

now, to produce an increased field, another similar layer of wound over the first, the number of turns will be doubled, resistance of the coil will be more than doubled, for the r of the outer layer will be greater than that of the inner. ing, however, the difference in diameter to be so small as no material difference in the length of the wire, the current

will be $$\frac{10}{10+5} = \cdot 66,$$

electro-magnetic field

$$0 \cdot 66 \times 20 = 13 \cdot 2.$$

larly, with a third layer, the current becomes

$$\frac{10}{15+5} = \cdot 5,$$

and the field

$$0{\cdot}5 \times 30 = 15{\cdot}0.$$

The multiplication of the layers, therefore, does not proportionally increase the strength of the field. On the other hand, the consumption of materials necessary to the generation of the current is reduced, and the economy of the system proportionally increased. If, therefore, a coil of 99 layers were employed, and supposing for the moment all the turns to be of uniform length and resistance, the arrangement would be very economical, for the current would be only

$$\frac{10}{495+5} = {\cdot}02,$$

while the field would be

$$0{\cdot}02 \times 990 = 19{\cdot}8.$$

But, of course, the length of wire composing the ninety-ninth layer would be considerably greater than that forming the first. Now, the circumference of a circle varies directly as its diameter, and is equal to $2 \pi r$, where π is the ratio between the circumference of a circle and its diameter, or $3{\cdot}1416$, and r is the radius of the circle. If, therefore, the diameter of the outside layer is actually twice that of the inside, the length of the wire in each of the larger turns, and consequently in the whole layer, will be exactly doubled, and its resistance doubled also; and the intermediate layers will vary proportionally. But the actual resistance of the whole coil can be easily calculated, for if the radius of the inside layer is half an inch and of the outside layer one inch, the mean or average radius will be three-quarters of an inch—that is to say, the length of wire in the fiftieth layer will be half as long again as that in the first. Its resistance will therefore be 7·5 ohms. Similarly, the resistance of the first and last layers together will be 15 ohms, or an average of 7·5 ohms per layer, and this will be true of every similarly situated pair of layers, so that the total resistance of a number of layers is equal to the resistance of the middle or average layer multiplied by the number of layers. In the coil under consideration the resistance will be

$$\text{R} = 7{\cdot}5 \times 99 = 742{\cdot}5,$$

and the current strength

$$\frac{10}{742 \cdot 5 + 5} = \cdot 0133,$$

and the electro-magnetic field

$$0 \cdot 0133 \times 990 = 13 \cdot 167.$$

If, now, we suppose the number of layers to be again doubled, and the mean radius increased thereby to 1 inch, the mean or average resistance will be 10 ohms per layer, and the total resistance of the 198 layers 1,980 ohms. The current then becomes

$$\frac{10}{1980 + 5} = \cdot 005,$$

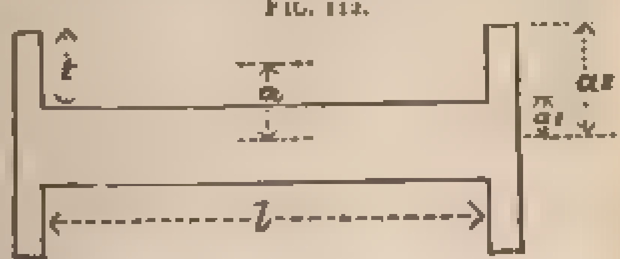
and the electro-magnetic field becomes

$$0 \cdot 005 \times 1980 = 9 \cdot 9.$$

The addition of layers of wire after a certain point has been reached has the result, therefore, of so increasing the proportional resistance as to reduce the effect which can be developed by any given battery, and this limit of usefulness or efficiency is reached when the maximum radius is twice that of the bottom or first layer.

When the field due to a certain coil, with inside and outside layers having resistances of 1 : 2, is insufficient for a given purpose, it may become advantageous to re-wind the bobbin with wire of a smaller gauge, so as to get a greater number of turns into the same compass. A reference to the diagram, fig. 112, will simplify the small difficulties involved in a consideration of this matter. Let us suppose the figure to represent a wooden or ebonite bobbin, and that the length, *l*, of the space occupied by the coil or the distance between the 'cheeks' of the bobbin, is inches, while the radius, a_1, of the bottom layer to be wound is a quarter of an inch, and the extreme radius, a_2, of the coil three-quarters of an inch. The mean radius a will be half an inch, or

FIG. 112.



$$a = \frac{a_1 + a_2}{2} = \cdot 5.$$

thus only three quantities known, viz. the dimensions of the bobbin, the resistance which the coil is to offer, and the specific resistance of the copper; while the length of the wire and its diameter are unknown and require to be ascertained. The space in which the wire is to be wound can be calculated from the given dimensions; for, V being this space or volume,

$$V = \pi\, l\,(a_2^2 - a_1^2), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\text{or } V = 3{\cdot}1416 \times 3(\cdot 75^2 - \cdot 25^2)$$

$$= 4{\cdot}7124 \text{ cubic inches.}$$

But supposing, as will be actually the case, that the wire, whose diameter is d, occupies the same space that it would take were it to be square instead of round, then, manifestly,

$$V = L \times d^2. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

As, also, the total resistance of the wire varies directly as its length, directly as its specific resistance s (which, in this case, we take as the resistance per cubic inch), and inversely as the area of cross-section of the wire,

$$R = \frac{L \times s}{area}.$$

But the area of the insulated wire is equal to $\pi\, r^2$, or $\pi\left(\frac{d}{2}\right)^2$, that is, $\pi\frac{d^2}{4}$.

Therefore $$R = \frac{L \times s}{\pi\frac{d^2}{4}},$$

that is, $$R\,\pi\frac{d^2}{4} = L\,s,$$

or $$R\,\pi\,d^2 = 4\,L\,s,$$

and $$d^2 = \frac{4\,L\,s}{R\,\pi} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

But from (2) it will also be seen that

$$d^2 = \frac{V}{L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Consequently $$\frac{4\,L\,s}{R\,\pi} = \frac{V}{L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and $$4\,L^2 s = \pi\,R\,V.$$

Therefore $$L^2 = \frac{\pi\,R\,V}{4\,s},$$

and, finally, $$L = \sqrt{\frac{\pi\,R\,V}{4\,s}} \quad . \quad . \quad . \quad . \quad . \quad (6).$$

By inserting the numerical values on the right-hand side of this equation, the length L, having the required resistance, can therefore be found, after which we can, by equation (4), determine also the gauge of the wire. It must, however, be noted that, for simplicity, d is taken as the diameter of the bare wire in equation (2), thus rendering the result only approximate; but when the thickness of the wire is great as compared with that of the insulation, the formulæ approach very closely to the truth.

It is frequently useful to know the exact length of any particular wire which can be wound on any particular bobbin, and, knowing V and d, this can be easily ascertained, for, if d_1 represents the outer diameter of the wire and its covering, V the volume of the wire-space, and L the required length, then

$$L = \frac{V}{d_1^2}.$$

So far, very little has been said concerning the dimensions and nature of the core, beyond the fact that it should have the highest possible degree of permeability, and be constructed, therefore, of the best annealed iron, and that there is a limit to the number of lines of force which can easily be passed through an iron core. These considerations render necessary the employment of a relatively massive core, having, for the best electro-magnetic effect, a diameter equal, at least, to the thickness of the coil with which it is to be surrounded—that is to say, its diameter should correspond to the thickness t in the ideal coil illustrated in fig. 112. It is here that the question of relative permeability has to be taken into consideration, for it has been experimentally demonstrated that there is a limit to the number of lines of force that can be transmitted by a given mass of iron, and that this limit is soon exceeded when the diameter of the core of an electro-magnet is small as compared with that of the coil which surrounds it. The permeability of a rod of iron decreases as the lines of force passing through it

portional to the current flowing through it. The third curve O C is particularly interesting. Suppose the magnetic effect due to the coil alone, and represented by the distance D F, to be deducted from the joint effect produced with the same current by the core and coil combined, and represented by the distance D A, then the remainder D C will represent the effect produced by the core alone. And if this subtracting process is carried out along each of the ordinates, the curve O C, known as the curve of magnetisation, will be produced. Now, it will be observed that, after a certain point has been reached, this curve becomes a nearly horizontal straight line, indicating that the saturation point of the iron has been reached, and that any further increase in the current strength does not add appreciably to the magnetisation of the core, the increase in the strength of the field developed being that due to the coil itself. The two curves O C, O B, would, if the experiments were carried far enough, intersect, at a point where the permeability of the air equals that of the saturated iron.

Pure soft iron has another property which recommends its adoption for the cores of electro magnets, and that is its low 'retentivity,' for, as a rule, electro-magnets are required to develop as strong a field as possible at some particular point directly the current commences to flow, and to lose or be deprived of all traces of magnetisation on the cessation of the current. Steel, as we have already seen, always retains a large proportion of the magnetic state impressed upon it by the projection of an electro-magnetic field through it, or, in ordinary language, it retains the magnetism imparted to it. Hard and impure iron have similar properties, inferior only to steel itself. There is no doubt that these properties of permeability and retentivity are very largely governed by the molecular structure of the iron or steel, and by the greater or less rigidity obtaining among the particles of the metal. In fact, the two properties go together; for all qualities of iron or steel through which it is difficult to urge the lines of force, or to magnetise, are found to be correspondingly obdurate when it is sought to demagnetise them, or deprive them of magnetisation. There is, therefore, a double gain in employing pure soft iron, for not only is its permeability greater, but its retentivity is also less than that of impure or hard iron.

On the other hand, in selecting a material for permanent agnets, the principal thing to be considered is the retentivity, hich, of course, should be as high as possible. No substance s yet been found which is, in this respect, superior to good hard eel. Some specimens of steel have been made so hard that orts to magnetise them have proved futile. One of the most markable features to be observed in this matter is the extra- dinary effect produced by the admixture of a small—one might most say a minute—proportion of other, or foreign, substances th the iron. Just as a fractional proportion of iron or other etal added to copper causes a large increase in its electrical re- tance, so the addition of carbon, tungsten, phosphorus, sulphur, enic, &c., to iron, reduces its permeability and also increases its entivity. This reduced permeability corresponds, in many pects, to increased electrical resistance in a conductor, and is, in t, sometimes referred to as increased magnetic resistance. In e case of ordinary steel the retentivity is evidently due, in a eat measure, to the presence of carbon, and, with a bar of good gnet steel, the permeability is so feeble, and the retentivity so eat, that it is impossible, by electro magnetic induction, to upset e molecular arrangement in the interior of the bar, so that the gnetisation is in reality only skin-deep. This can be easily oved by magnetising a small piece of very hard steel and then mersing it in dilute sulphuric or hydrochloric acid. In a few ments the surface of the metal will have been dissolved, and on thdrawing it from the liquid all trace of magnetisation will have appeared. Consequently, it is preferable, in making a large rmanent magnet, to build up a number of thin strips of steel t to size and then magnetised separately. On fastening them gether, the built-up, or 'laminated,' magnet will be found capable producing a far stronger field than can be obtained with any id magnet of similar dimensions. It should, however, be added at in building up a compound magnet, or 'magnetic battery,' ere is no advantage in employing *brass* screws or bolts to fasten e individual magnets together as is usually done. In fact, this n cannot but disperse the lines of force passing through the gnets, and therefore weaken, more or less, the polar strength. on screws or bolts are mechanically and magnetically preferable.

It is interesting to notice that specimens of steel hav made, containing 12 per cent. of manganese, which it has found practically impossible to magnetise even under the infl of a very powerful field. Probably, the magnetic reluct molecular rigidity, magnetic inertia, or whatever else we may c to call that property of steel which our forefathers knew as co force, is so great, that to overcome it is impossible. Similar r follow when the proportion of carbon, phosphorus, sulphur mixed with the iron exceeds a certain small limit, while the ad ture of even the smallest percentage of antimony suffices, alleged, to destroy all trace of magnetic properties. There s certainly be a large field of practical utility open to the econo manufacture of unmagnetisable iron. For example, the bed-p of dynamos are sometimes—and used to be even more exten than now—separated from the field-magnets by huge slabs of because, otherwise, they would form what may be called a mag short-circuit between the poles of the field-magnets. Zi mechanically much weaker than iron, and this, added to it much higher price, renders its use highly objectionable To the difficulty, dynamos are rarely designed now with their pieces downwards, but are turned about so that the bed is connected to the yokes or magnetically neutral portions o field-magnets. Under such circumstances only a very few o lines are wasted by passing through the bed plate. Reverti the question of magnetic inertia, it may be mentioned th cause which may operate to set up molecular vibrations in a of iron or steel facilitates either magnetisation or demagneti —that is to say, if the metal is placed in a magnetic field and vibrations set up in it, it will be more readily and more pow magnetised than would be the case were the vibrations not s and, conversely, a magnet loses its magnetisation by being s vibration, due to the fact that facilities are thereby afforded f individual particles, which are themselves magnets, to partially and form little closed magnetic circuits in the mass of the These vibrations can be caused by heating, hammering, tw or any other similar violent treatment. Hence, steel mag should always be placed down gently, and never dropped or th down, otherwise the magnetisation will be more or less destro

gnet raised to a red-heat loses its magnetisation entirely, his can easily be demonstrated by heating a magnetised sew-eedle in a gas flame.

y adopting the precautions referred to, magnets can be capable of sustaining considerably more than thirty times own weight, but a description of the method practically ted for the manufacture of permanent steel magnets capable ome years of supporting about twenty-five to twenty-eight their own weight may prove serviceable. In this case, the best ten steel is employed. It is heated gently to a dull red heat and nered into the required shape, care being taken not to raise mperature too high, or the tungsten will be volatilised. A magnet may therefore require to be placed in the fire several before the necessary shape has been obtained. This pro-being completed, the steel is then hardened by being first d in a close fire out of contact with air, so as to ensure uni-heating and to prevent the formation of a hard scale of iron It is then dipped into a water bath. This latter process be carefully attended to, or the metal will be twisted or wise distorted. It should be held vertically, and, if of the shoe pattern, its extremities should be dipped in first, the being steadily lowered into the water. The next process is of polishing, after which it is passed a few times over the of a large and powerful permanent magnet, the steel being d over once or twice so as to magnetise both faces. Of e, a large electro-magnet, with a powerful current circulating gh its coils, can be employed, but the other form is quite nt and certainly much less troublesome.

e have not yet, however, said all that requires to be said the subject of electro magnets. One important detail, so far cted, is the length of the coil and of the core, as compared the diameter. It has already been laid down that the mum, or outside, diameter of the coil should not exceed three the diameter of the core; but although it is often stated he best result is obtained when the length of the core is six its diameter, we have failed to discover any universal reason ch a proportion. As a matter of fact, with a bar-magnet, e we desire to employ only one pole, and wish to mask or get

rid of the effect of the other, there is a decided advantage in using a core of much greater proportional length, and if we are restricted as to the quantity of wire to be employed, we can then wind fewer layers over a long piece of iron than would be wound over a shorter piece. By so doing we should reduce the distance between the iron and the wire, and therefore, with the same resistance, the number of lines of force passing through the core would be correspondingly increased. Supposing, however, the same proportion to be maintained between the respective diameters of the lengthened core and its coil, and the gauge of the wire increased so as to maintain a constant resistance and constant number of turns, the polar strength developed close to one end of the core will vary as the square of the length of the core, providing, however, that the core is not so extensively lengthened as to cause many of the lines of force to 'leak out' at the sides of the coil. This limit will, of course, vary with different qualities of iron, as the question is mainly one of relative permeability. Sometimes there is an advantage in using very short electro-magnets, as for example, when it is desired to obtain one which shall respond promptly to variations or reversals of the magnetising current.

So far, we have only considered electro-magnets in which the wire is wound evenly throughout their length, but, for some purposes, it is preferable to vary the method of winding. If, for example, it is desired to construct a bar magnet which shall develop a very powerful field close to its extremities, but which is not wanted to exert any force at a comparatively greater distance, then the best form to give to the piece of apparatus is that in which the wire is 'coned up' near the ends—that is to say, where a large number of layers is wound over the ends, the number decreasing towards the middle, few or none being wound over the central portion of the core, although at no point should the wire, as a rule, be wound to more than three times the diameter of the core. The lines of force in such an electro-magnet will be powerfully developed near the ends, and there will be little tendency for them to leak out. On the other hand, they will make much smaller air-curves than would result from an equal length of wire wound evenly along the entire length of the core.

The horse-shoe form is only adopted when it is desired to

exert the maximum attraction upon a piece of iron placed near it. If it were placed at any considerable distance compared with the distance between the magnet poles, most of the lines of force would pass across the air space from one pole to the other without entering the iron. But such a magnet obeys the same law that holds good for bar magnets so far as the relative strength of the magnet, when traversed by various currents, is concerned. That is to say, if we have an electro magnet developing a field, at a given distance the strength of the field will vary directly as the strength of the current producing it. When, however, a piece of soft iron is placed in the field, the lines of force are diverted, and, passing through it, endow it with magnetic polarity, and the polarity developed varies directly as the number of lines passing through it, or as the strength of the current. Such a piece of iron is called an armature, but we may regard it for the time being as another magnet, and when we have two magnets mutually attracting one another, the force of attraction is proportional to the product of their magnetic strengths, or the force

$$f : m \times m_1,$$

where m is the strength of one magnet, and m_1 that of the other (or of the armature).

If, now, we suppose the strength of the current to be doubled, and consequently the magnetic field developed to be also doubled, then (assuming the iron to be far from saturated) twice the number of the lines of force will pass through the armature, the magnetisation of which will therefore also be doubled, that is

$$f_1 : 2m \times 2m_1 = 4mm_1,$$

or, doubling the current strength, quadruples the magnetic attraction Hence this attraction at any given distance varies directly as the square of the strength of the current flowing through the coil When, however, the iron approaches saturation, the alteration in its permeability prevents any definite law being formulated.

This law is sometimes mis-stated by saying that $m = m_1$, hence $m \times m_1 = m^2$. But this is only true when the whole of the lines of force emanating from the poles of the electro-magnet pass through the armature, and this rarely or never happens.

To ensure that the armature shall be capable of transmitting a large percentage of the number of lines of force which pass through the core, it is evident that it must at least be equal in permeability and correspondingly massive. It should certainly be equal in section to the core.

One of the best forms of the horse shoe magnet is that illustrated in fig. 111. It will be seen that the coil is divided into two sections, placed one on each limb or leg of the core, the winding being such that, were the core straightened out and the coils pushed together so that their ends meet, they would form one continuous coil or helix. Otherwise similar instead of dissimilar poles would be developed at the extremities of the core. The iron should be the best and softest procurable, and should be bent round so that the poles are close together; a comparatively very large number of the lines of force will then pass through the space between the poles when the armature is removed. The surfaces in contact should fit as perfectly true as possible, so that there is the minimum air space between them. Sharp corners or edges should be avoided, and, since the natural shape of the lines of force is circular, the whole should approximate to the circular form, when there will be little tendency for the lines of force to 'leak out' of the iron and complete their circuit through the air space.

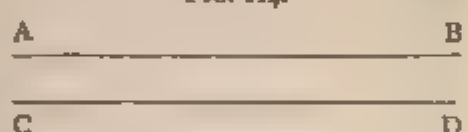
Horse-shoe electro-magnets are frequently constructed to sustain a weight. The sustaining power must not, however, be confounded with the strength of the field or the magnetic strength, as this power depends upon a number of secondary considerations, such as the shape and smoothness of the pole pieces or extremities of the core, the dimensions and surface of the armature, the method of applying the weight to be sustained, &c., which do not require to be taken into account when estimating the electro-magnetic field itself. The weight can be suspended from a hook fixed to the middle of the armature, so that the pull upon the two poles is equal, the sustaining power being measured by the weight which can be supported by the armature without causing its separation from the magnet.

It is, however, frequently preferable, for convenience of construction, as in the case of most forms of dynamo-electric

machines, as well as in telegraphic and other similar apparatus, to build up an electro-magnet in which two straight cores are yoked together by a piece of soft iron which is screwed or bolted to them. The yoke must naturally be massive, and the surfaces fit truly to avoid as far as possible the introduction of a magnetically resisting air space.

We have stated frequently—so frequently, in fact, that we almost feel it necessary to apologise for repeating the statement—that when a current of electricity is set up in a wire, an electro-magnetic field is almost immediately generated in the region surrounding that wire. But the converse of this is also true viz. that when an electro-magnetic field is suddenly set up around a wire, there is a tendency for a current to be generated in that wire *during the setting up of the field*, and if the wire forms part of a complete circuit a current will flow along it. The source of the field is immaterial: it may be a permanent magnet, a straight wire or a helix carrying a current; all that is essential being that the lines of force should be thrust across the wire, or that the wire should be moved in such a manner as to cut the lines of force *transversely*. As an instance, let A B, C D (fig. 114) be two wires running side by side for a certain distance, each forming part of a complete circuit. If a current is started in A B, lines of force will immediately start from its centre, or axis, in the form of widening circles, and, cutting the second wire, C D, set up an electro-motive force therein and, in consequence, generate an electric current. It is only, however, while the lines of force are actually cutting the second wire that the E.M.F. is developed, and as this cutting ceases immediately the current in A B arrives at its full strength, the induced current lasts but for a moment. In direction it is opposite to the current in the wire A B. While the original current is steady many of the lines of force due to it are embracing the adjacent wire C D, though, being relatively at rest, they have no effect thereon.

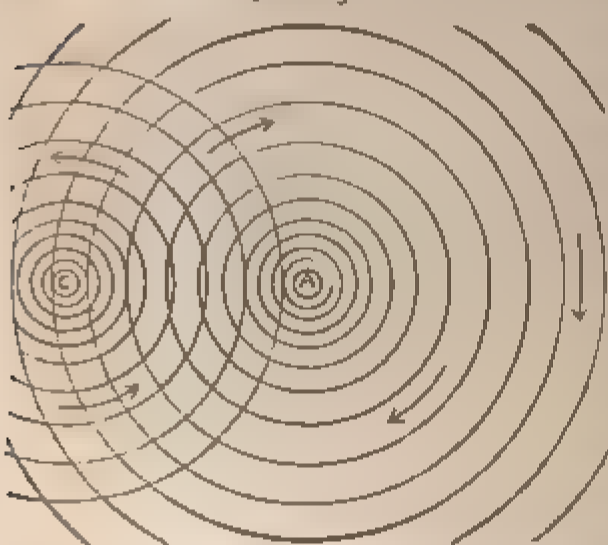
FIG. 114.



But when the current in A B is stopped, all the lines of force collapse upon it, and those which extended beyond the wire C D again cut it, and thereby induce in it another momentary current.

But, since the lines now cut the wire C D in the opposite sense (for they approach it from the opposite side), the resulting current is in the opposite direction to the previous one—that is, it is now in the same direction as the inducing current which was flowing in the wire A B. By noting the direction of the lines of force due to the inducing current, and the direction in which they must coil round the wire C D during the time they are passing it, we might predict the *direction* of the induced current in either case. It is somewhat difficult to make this clear by diagrams, but an analogy may assist us to a great extent. When any small body is dropped on the surface of still water it breaks that surface into a series of ripples which take the form of ever-widening concentric circles, as in fig. 115, where A is the point of generation. In such a manner do the lines of force spring into existence from a wire, only with far greater rapidity, and it is difficult in either case to fix a limit to their extent if the medium (the water or the ether) is not limited.

FIG. 115.



Now, if these water ripples meet any obstruction, for instance, a post at the point C, they set up around it a series of circular ripples, feebler, perhaps, but precisely similar in character to themselves. It is difficult at present to say with certainty exactly what happens in the case of the electro-magnetic lines of force, but we can safely use the analogy for the purpose of demonstrating that the direction of the lines of force round the wire in which the current is induced is opposite to their direction round the inducing wire. For, suppose, as in the case of the lines of force, the original ripples round A to have what is called a positive direction—that is to say, that they circulate in a right-handed direction after the manner of the hands of a clock, as indicated by the arrows; then, since that direction would not be altered by

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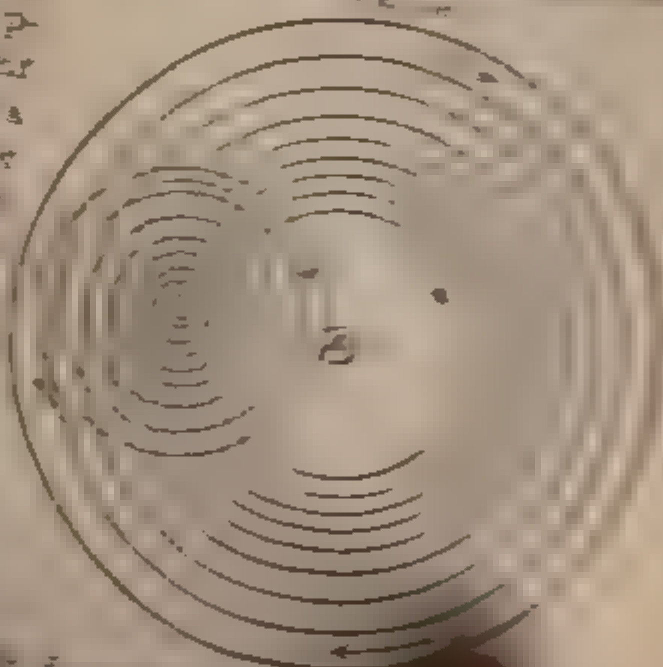
Fig. [illegible]



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it stop suddenly; time is taken for the lines of force to spring into existence and to die away, and under certain conditions this time may be considerable. To understand the principal cause of this sluggishness let us refer again to fig. 115 and further study the case of the water ripples. A little thought or experiment will make it evident that the secondary ripples round C will quickly reach the point A, and if the body which caused the disturbance is still there, will set up around it ripples in the opposite sense to the original ones. Now, suppose two wooden balls, A and B, were dropped into the water at the same moment close together and equidistant from C, they would set up ripples round C, each to the same extent and in the same sense; in fact, the number round C would be doubled. But still stronger is the effect of A and B round each other, and (still assuming a positive direction just as we do for lines of force) the direction of the ripples so set up round each will be opposite to those which it generates. In the same way if a primary wire is looped into two convolutions, A and B, they will generate round an equidistant loop of the secondary just double the number of lines of force which one will; but they also react upon each other, each setting up round the other, lines of force which would generate a current tending to stop the primary one, the result being that this primary current does not rise so rapidly to its full strength. This retardation increases as we increase the number of convolutions; in fact, it varies directly as the square of the number of convolutions, because each one acts upon all the others and they in their turn act upon it. Therefore the retardation in a coil of 100 turns would be 100 times as great as in a coil of 10 turns.

In a precisely similar manner the reaction of adjacent convolutions prevents the instantaneous *stoppage* of a current; for, at the moment of disconnecting the battery or other current-generator, lines of force collapse upon each convolution, and in so doing they cut the other convolutions and generate a direct induced current which will also vary as the square of the number of turns, and tend to prolong, or retard the disappearance of, the primary current.

The electro-motive force resulting from this collapsing of the lines of force may be, and usually is, much higher than that which maintains the original current. For, supposing the battery

used consists of ten Daniell cells, then if the poles are connected by a short piece of wire, no spark, or, at the most, a very feeble one, is observable when the circuit is closed or opened quickly. If this same battery is made to send a current through a coil of many turns of wire, although its resistance may be high and cause the current to be comparatively weak, yet, on breaking the circuit, a spark will be observed. This is due to the fact that the lines of force fall back so quickly upon their respective convolutions in the coil, that they cut the adjacent convolutions with sufficient rapidity to generate a momentary E.M.F. high enough to produce a current sufficiently strong to volatilise a portion of the metal, and to maintain the current across the vapour-filled space for a brief interval, even after the wires are moved asunder. This effect is even more striking if in a dark room contact is broken between a wire and a mercury surface, when a little of the mercury is volatilised; and, since the effect of iron placed in the vicinity is to increase the number of lines of force which are active, the spark can be increased enormously by placing a core inside the coil.

The term 'self-induction' has been given to this action, which prevents the instantaneous rise and fall of a current, and it will be evident, from what has been said, that, in the case of a simple straight wire, this phenomenon is almost imperceptible, and that, in order to make the self-induction of any circuit a maximum, the wire should be wound into as many convolutions as possible, and be provided with plenty of iron.

In some cases it is desired to design electro-magnets which shall be affected as little as possible by brief, sudden fluctuations of the magnetising current. It is manifest that in such a case the electro magnetic inertia—that is, the self-induction—must be made high by using a long and massive core and a great number of turns of wire; for, as we have seen, self-induction prevents a rapid rise or fall of the current, in just the same way as the 'inertia' of matter prevents any instantaneous change in its motion. If, on the other hand, an electro-magnet is required to be quick acting, or to be very sensitive to any variation in the current, self-induction should be as low as possible, and, in order to obtain this, the coil should consist of as few turns of wire as possible, and the core

ould be very short, or the turns of wire should be confined to e end or ends.

The measurement of the intensity of an electro-magnetic field , as already mentioned, a matter of great practical difficulty. However, as the movement of a wire in any magnetic field tends set up a current in the wire, and as the field may be that of a ermanent magnet, or even that of the earth, and since, also, the rength of any field is proportional to the number of its lines of rce per unit area, while the current generated in a wire is also roportional to the number of lines of force cut by it, and to the te of cutting, we may compare the strength of different fields by bserving the current resulting from the cutting of them by a wire t equal speeds. It is advantageous to wind the wire into a small oil, and place it in the field with its plane perpendicular to the irection of the lines of force, and then suddenly turn it through right angle, when its plane will be parallel to the lines of force, nd none will be passing through the coil. The E.M.F. resulting ill be proportional to the number of convolutions, the strength of field and the area of the coil (that is, to the number of lines of force passing through the coil), and to the speed with which the lines are removed. Special galvanometers are constructed to give the values of such sudden momentary currents, by comparing which the strengths of the various fields can be measured.

CHAPTER VIII

DYNAMO-ELECTRIC MACHINES (ALTERNATE CURRENT).

IN the preceding chapters we have dealt with some of the princip laws of electric currents, and the most striking phenomena co nected with them. The student will not have failed to noti two important facts: (1) That when a wire through which a cu rent is passing is placed in a certain position in any electro-ma netic field, it has impressed upon it a definite mechanical for tending to move it into another part or out of the field; an (2) when a conductor is mechanically moved in a field tran versely to the lines of force traversing that field, a certain electr motive force is determined, which sets up a current in the wire its two ends are connected. Extensive use is made of both the effects in practice, and on a very large scale. Machines which a constructed to transform energy which exists in the form of electr currents into energy in the form of mechanical motion, and, co versely, machines which are able to transform energy in the for of mechanical motion into energy in the form of electric curren can be included under the generic head of 'dynamo-electr machinery.'

We shall first consider machines of the latter class, which a commonly known by the shorter name of 'dynamos,' deferring consideration of the other class until an opportunity offers f dealing with such apparatus under the head of 'motors.'

In every machine for the conversion of energy, there is alwa a certain amount of loss attending the conversion; in other word less energy appears in the new than existed in the original for The more perfect the machine, the less does this loss become, that a theoretically perfect machine would be one in which the is actually no loss at all. It is absolutely impossible to constr

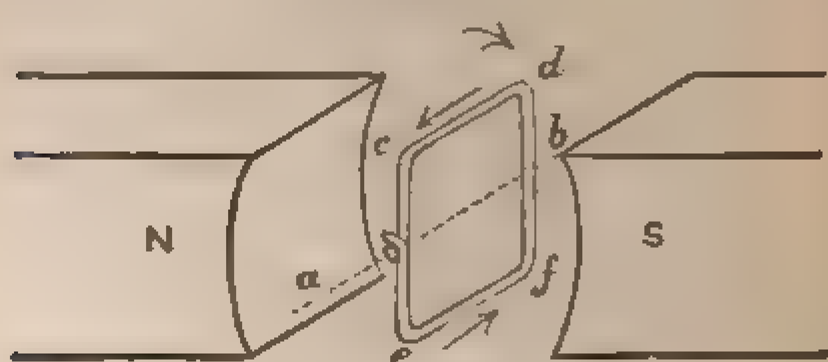
ch a machine, but in every case the chief aim of the engineer hould be to make the loss as small as possible, or to make the achine as 'efficient' as possible. The proper way of doing this to start with the fact established in accordance with the doctrine the 'conservation of energy,' that energy can never pass out of xistence or be destroyed; that, therefore, the whole of the energy ut into the machine reappears in some shape or form, although nly a part appears in the exact state in which it is desired. Steps hould then be taken to ascertain exactly what form the other part kes, and the designer of the machine should study how to reduce at same part, which may be called 'waste,' to a minimum. In machines which have moving parts, a certain percentage of the ergy takes the form of heat, due to friction at the bearings and her surfaces which come into contact. Every dynamo has oving parts, and is therefore subject to loss from this cause, and e well-known methods of reducing friction by good workmanship d design, and by the judicious use of oil or other lubricant, are ken advantage of to minimise the loss. But there are many her causes besides mechanical friction which operate to reduce e efficiency of a dynamo; they are mainly due to electro magtic phenomena, and careful study is required in discovering how eliminate or minimise them, although in some instances the s may be readily localised, because, like friction, these phenoena convert a certain amount of the original energy of mechanical otion into heat. One of the principal features, then, by which a ynamo is judged is its efficiency, or by the ratio of the energy appearing as electric currents to the total amount given mechacally to the machine.

We will start with the consideration of the simplest type of namo electric machine, and, observing its weak points, endeavour trace its development into a practical and highly efficient piece apparatus.

Now, it is only during the time that the lines of force of a field being cut by a conductor that an E.M.F. is induced in that nductor; therefore, in order to obtain a continuous current, or very rapid succession of currents, it is evident that either the nductor or the field must be kept continually in motion. Let first study the case of a fixed field and a moving wire, assuming,

for the moment, that we have a strong and fairly uniform f produced by the opposite poles of two large permanent bar-magn placed near to each other, or by any other convenient means. uniform field has been already defined to be one in which lines of force are straight, parallel, and equidistant. It is not e to obtain a strong uniform field of any great extent, so that most convenient way of continually cutting lines of force is cause the conductor to move in a circular path, within the lim of a powerful field of comparatively small area For instance, the wire is bent into a single rectangular coil, as shown in fig. 11

FIG. 117



it may be placed in the field with its plane at right angles to direction of the lines of force, so that as many as possible of th lines are made to pass through it. If, now, this coil is turn suddenly through an angle of 90° about the axis *a b*, its plane parallel to the lines of force, and it is obvious that none of th now pass through the coil. In the act of turning, both the and the bottom limbs, *c d* and *e f*, cut a certain number of lin setting up thereby an electro-motive force in the wire; but these two horizontal limbs of the rectangle cut the lines fr opposite sides, the direction of the resulting currents in them opposite. In the lower limb, *e f*, the direction is from front back, and in the upper one, *c d*, from back to front. Both curre therefore, pass round the coil in the same direction. The limbs of the rectangle—that is, *c e* and *d f*—simply slide, or through the lines of force, and do not *cut* them; they, theref have no current induced in them, and, while adding to the re ance of the loop, are useless, except for the purpose of comple the electrical circuit. The student may now, with advant

n read the paragraph in Chapter IV. which indicates how the ction of an induced current can in every case be predicted. the present case the lines of force go from left to right, and the ber cut by each limb, so far, is half the total number originally sing through the rectangle.

When the rectangle is turned through another 90°, so that the b which was at first uppermost is now at the bottom, it has the imum number of lines of force suddenly thrust through it in; another induced current is the result, and as, during the vement, both the horizontal limbs cut the lines from the same e as they did in the first movement -that is to say, one limb l cuts downwards and the other still cuts upwards the direc- n of the current is the same as that developed during the first rter of a revolution. Further, as the number of lines of force t is in each case the same, the induced E.M.F. is also the same, vided the rates of moving are equal.

If, therefore, the rectangle is rapidly turned at one sweep from original position in fig. 117 through 180°, a current will be uced, in the direction shown by the arrows, during the whole hat movement. If the rotation is continued, on passing the 180° horizontal limbs again begin to cut the lines of force, but they e cut them from their opposite sides, or in the opposite direc- n to that during the first half revolution. The resulting current herefore in the opposite direction to the previous one, but of cisely the same strength if the motion is uniform. A con- ous rapid rotation of the rectangle then, will give rise to a es of currents alternating in direction, two distinct currents ng generated during each complete revolution, the reversal ing place every time the rectangle passes the points at which plane is at right angles to the lines of force.

Supposing both the field and the speed of rotation to be form, the question arises whether the E.M.F. is also uniform ng, say, the whole time of a half revolution. As the induced I.F. is proportional to the *rate* at which the lines of force are it is only necessary, in order to decide this question, to ascer- whether the rate of cutting is, under the circumstances, also form. A little reflection will show that just when the rectangle ns to move from its position in fig. 117 it is *cutting* hardly

[illegible]

[illegible]

field is uniform, the coil cuts a much greater number of lines force by moving through 30° when its plane is nearly parallel to direction of the lines than it does by moving through an equal gle while it is nearly perpendicular to them. But as the speed rotation is uniform, it takes precisely the same time to pass ough these equal angles, therefore the rate of cutting, and sequently the E.M.F., must be much greater in the former than the latter case. In fact, the rate at any moment is proportional the *sine* of the angle through which the coil has then moved m the vertical position.

We have defined a magnetic field of unit strength to be one ing one C.G.S. line of force per square centimetre, and if a ductor one centimetre in length is moved transversely through s field at a velocity of one centimetre per second, it will cut one e of force per second, and thereby develop one C.G.S. unit of ectro motive force. If either the strength of field, the velocity, the length of wire be doubled, the resulting E.M.F. will be bled, the number of lines cut per second being increased two-d. If we simply know the number of lines of force cut per ond, the E.M.F. can be calculated without any consideration as the length of conductor or strength of field. If the field is uniform, however, or if the wire moves at a varying speed, the of cutting, and therefore the E.M.F., will fluctuate. But the *rage* of this fluctuating E.M.F. will be equal to the average rate cutting, that is to say, it can be found by dividing the whole mber of lines cut by a conductor, by the time in seconds upied in the cutting. If, therefore, the rectangle in fig. 117 kes one revolution per second, and the maximum number of s of force embraced by it in the zero position is denoted by N, n each limb will cut 2 N lines per second, because it cuts the ole number N during the downward sweep, and again during upward movement. Consequently each limb develops an rage E.M.F. of 2 N C.G.S. units, and as both limbs are connected ries the total E.M.F. becomes 4 N units. Further, if the rect-le makes *n* revolutions per second instead of only one, then *n* s as many lines will be cut per second, and the average E.M.F. be 4 N *n* units. But since the C.G.S. unit of electro motive is so very small, a much greater practical unit, called the

volt, equal to 100,000,000 C.G.S. units, is employed. [illegible] obtained in C.G.S. measure must, therefore, be divide[illegible] number to give the value in volts, and the simple equ[illegible] be written,

$$\text{average E.M.F.} = \frac{4\,N\,n}{100{,}000{,}000} \text{ volts.}$$

It may be mentioned that the value of N is, in actual [illegible] very high, being, as a rule, several millions. In practic[illegible] average E.M.F. which concerns us most, but we may ob[illegible] if the rectangle were rotated at a constant speed in [illegible] field, the actual E.M.F. being developed at any momen[illegible] had moved through an angle *a* from the zero position w[illegible]

$$E = \frac{2\pi \sin a\,N\,n}{100{,}000{,}000} \text{ volts.}$$

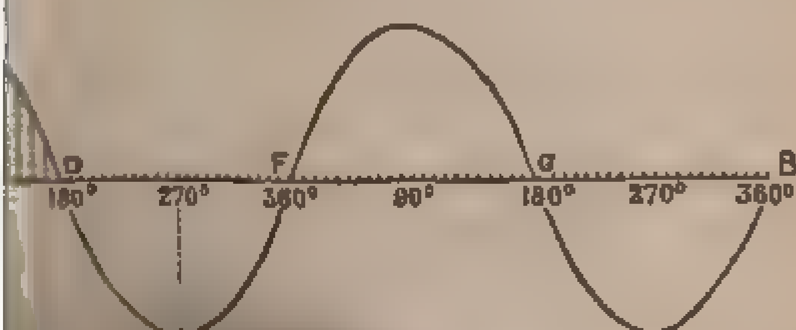
The above refers to the case of two active wires, formin[illegible] a rectangle and joined up in series in such a manne[illegible] E.M.F. of one is added to that of the other. The resul[illegible] is twice that developed by one active limb; and if the[illegible] wound in a number of convolutions, it would be ne[illegible] multiply by the number of active limbs then joined in seri[illegible] of by 2, as in the present case) to obtain the total E.M.F.[illegible]

The function above referred to as the 'sine,' is one [illegible] the student will frequently come in contact. Perhap[illegible] it will now be as well to explain briefly what is meant [illegible] of an angle. If in one of the two straight lines which [illegible] angle, such as E [illegible] . 119, any point, say E, is taken [illegible] it a line E R is d[illegible]endicular to [illegible]er line, a [illegible] triangle, E X R [illegible] The len[illegible] perpen[illegible] divided by t[illegible]e hyp[illegible] that [illegible] definite value, [illegible] the [illegible] may be, provid[illegible] X R is [illegible] E R [illegible] E [illegible] an[illegible] sin[illegible] X [illegible]

minator, as will be the case if it forms the radius
qual circles, as F X and A_1 X, and let it be equal to
sine is simply measured by the numerator E R or
the length of the perpendicular. When the angle
mall, the perpendicular, and therefore the value of
ecomes very small ; in the case of the imaginary
erpendicular disappears, the sine of 0° being 0.
le is 90° the perpendicular coincides with and is
ius. The sine of 90° is therefore 1, and this is the
e value of the sine. It decreases as the angle
s, until, at 180°, its value is again 0. From here it
egative, the sine of 270 being — 1. By referring
as that on p. 98 the value of the sine of any angle
found, and we can, therefore, calculate the relative
E.F. at any position of the rectangle, and also show
how the E.M.F. should rise and fall in a perfectly

he portion A F of the horizontal line A B represents
rned out, each of the four equal parts into which it

FIG. 110



being equival 90°, that is, a quarter of a
rectangle. this line A F might be sub-
parts to rep 360 degrees, and any point
n be taken the position of the rect-
d through a g angle from zero. Now
that the E.M nt is proportional to the
ngth which then turned from zero;
take a ts along this line, and
rtional in length to

the sine of the angle which that particular point represents. During that half of the revolution in which the sines are reckoned as negative the perpendiculars should be drawn below the line, indicating the reverse direction of the E.M.F. and current. For instance, at 90° the sine will have the greatest value, viz. unity, while at 45° the perpendicular will be only 0·707 of that at 90°, because the sine of 45° is 0·707; at 270° the sine is − 1, and therefore the perpendicular equal in length to unity is drawn below the line.

By joining the extremities of these perpendiculars we obtain a curve known as a sine curve, which at a glance indicates the manner in which the E.M.F. rises and falls during one complete revolution of a simple coil; and the whole of the curve from A to B shows the fluctuation of the E.M.F. during two revolutions.

If in fig. 119, E X is taken as unity, it may represent the height of C or E, the highest points on the sine curve, and then E G will be the length of the perpendicular representing the electro-motive force at 60°, for E G is the sine of the angle E X G, which is the angle (60°) through which the coil has turned from the vertical position. Similarly, A_1 C (fig. 118) will represent the E.M.F. developed when the coil has turned through 30°, for A_1 C is the sine of that angle.

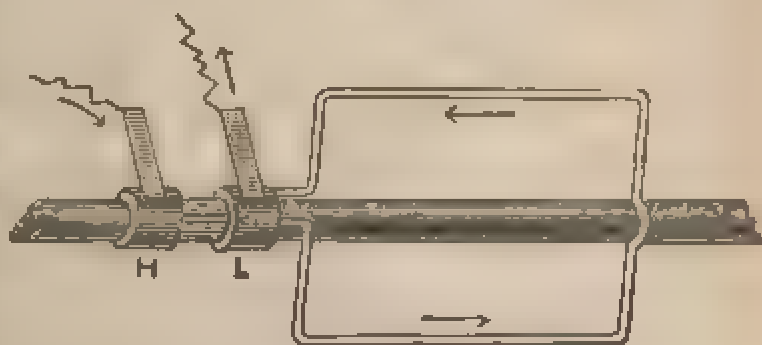
The curve (fig. 120) shows that the E.M.F. at 90° is equal to that at 270°, but that it is positive in the one case and negative in the other.

Referring again to figs. 118 and 119, we observe that the 'effective area' of the coil, with respect to the lines of force which it embraces in the position A_1 B_1, is proportional to A_1 L, and in the position E F to E K; that is, A_1 L and E K are proportional to the number of lines of force passing through the coil in the two positions. Now, $\frac{A_1 L}{A_1 B_1}$ is the cosine of the angle through which the coil has already rotated, for the angles A_1 X A and P A_1 X are equal, or it is the sine of the angle which the coil makes with the direction of the lines of force; as is also $\frac{E K}{E F}$. Taking, for simplicity, the equal lengths A_1 B_1 and E F as unity, we see that the number of lines of force passing through the coil in any position

in a uniform field is proportional to the cosine of the angle through which it has been turned from its position at right angles to those lines, and also to the sine of the angle which it makes with the lines of force.

These variable alternating currents, depicted in fig 120, being thus developed by the rotation of the wire rectangle, some device is required to enable us to lead them away to an external circuit and there make use of them. The rectangle might, for this purpose, be mounted on a wooden spindle (fig. 121), and its ends connected to two flat metal rings, H L, fixed a little distance apart on the spindle, contact being then made by means of a flat spring, or a wire brush, pressing against each of the rings. By attaching wires to these contact brushes the currents can be conducted away to any desired point.

FIG 121.



It remains now to show to what extent, in practice, we can comply with the conditions which theory teaches us will tend to make the E.M.F. high.

For a small machine, permanent magnets may be used to supply the field, and for this purpose a horse shoe magnet is found to be very convenient, but it should be bored out or fitted with soft iron cheeks, of such a shape that there is just sufficient room for the wire coil to rotate between them. The steel should be strongly magnetised, and, if of considerable size, it should be laminated, or built up, of a number of thin magnets with their like poles adjacent. A circular magnet (fig 122), divided at one part of the circle, and with just sufficient space bored out for the coil to rotate, is better than one of the ordinary horse-shoe pattern, although not so easy to make. Having obtained the magnetic field, the next thing is to get as many as possible of the lines of force to pass through the coil of wire. Iron here comes to our assistance once more, for, by winding the rectangle round a core

of pure soft iron, we concentrate those lines which would otherwise stray, and the number passing through the wire is greatly increased. It is almost superfluous to add that the actual area of the rectangle should be as great as possible, provided that it is kept within the limits of the field, and since, as we have seen, the induced E.M.F. is proportional to the number of active conductors joined in series, the wire may be wound into a coil consisting of a number of turns instead of only one. Now, a coil in which currents are induced by its movement within a magnetic field is generally called an 'armature.' The core of one of the earliest forms of armature is shown in section at A, between the poles of the circular magnet F, in fig. 122, and although, when criticised in the light of our present knowledge, the design proves to be very faulty, it will serve very well to illustrate the principle. A view of this armature is also shown in fig. 123. It consists of a considerable length of silk- or cotton-covered copper wire, wound in the grooves of a shuttle-shaped piece of soft iron, A B, which is usually about twice as long as its greatest width. It is provided at one end with a driving pulley, *p*, and at the other end by a device for communicating the current to the external circuit.

Fig. 122.

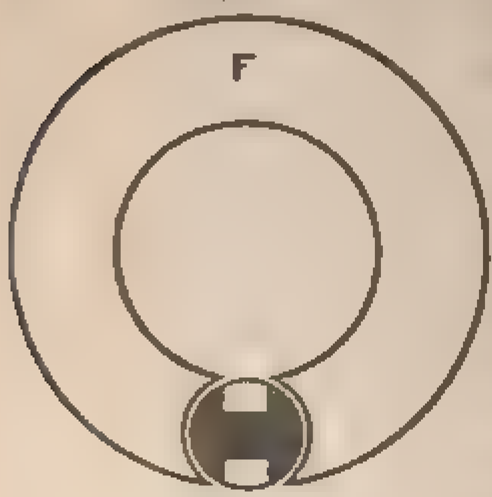


Fig. 123.

Good effects can be obtained by rotating such an armature in a strong field. The speed of rotation must be high, but this can readily be obtained by any mechanical multiplying device, such as a pulley of large diameter driving a smaller one on the armature spindle. Although the E.M.F. increases with the number of turns of wire on the armature, it is found that this increase is not by any means proportional,

[illegible]

In the case in question, the best method is to 'laminate' the armature, or to build it up with a number of small discs cut to the required shape and bolted together, instead of using a solid piece of iron. The iron must be continuous in the direction in which the lines of force have to pass through it, otherwise the efficacy of its action in concentrating these lines would be seriously impaired, while it must be discontinuous in the direction in which the eddy currents tend to flow, viz. at right angles to the lines of force. To meet these requirements the discs threaded on the spindle must be well insulated one from another, although, on account of the low E.M.F., a sheet of thin paper or a layer of varnish is, as a rule, sufficient. It is hardly necessary to adopt this precaution in the kind of machine we have been considering, which is very small, and only made to be driven by hand power, but it becomes absolutely necessary, as well as economical, in the larger machines driven by steam power. At first sight it would appear, remembering that the E.M.F. developed in the armature coil varies as the rate at which the lines of force are cut, that the E.M.F. of a magneto-electric machine should be simply proportional to the speed of rotation, the strength of the field being invariable. But there are several causes which tend to prevent the increase of the E.M.F. developed by the augmentation of speed attaining this proportion, the principal being the eddy currents produced in the core, the electro-magnetic reaction of the current in the armature upon the field produced by the field magnets, and the self induction of the armature. It is important to notice that when a current is flowing round the armature coil the whole armature is in reality an electro-magnet, and it acts as such upon the poles of the permanent horse-shoe magnet which supplies the field, this reaction, as in every similar case, tending to stop the motion of the armature. If, however, the armature is forcibly rotated against this tendency, the result is that the magnetic field is distorted and dragged somewhat out of its true position, and, as the current in the armature rapidly alternates from zero to a maximum, this dragging effect will also vary considerably, with the result that the field will be kept in a state of oscillation and its uniformity destroyed. The maximum current in the armature becomes higher as the speed is increased, and the distortion of the field is then greater, the result

a tendency to prevent the E.M.F. rising in proportion to the . Furthermore, as the iron core has a greater number of of force passing through it when the current increases, its ability may also become appreciably lower.

sides the waste due to eddy currents, which increases very y with the speed, the effect of the self induction of the arma- lso becomes strongly marked, this latter not only preventing a high E.M.F. being attained, but, in addition, retarding the nd fall of the current. In fact, were we able to plot a curve ng the rise and fall of a current in this shuttle armature, we d find it somewhat similar to that given in fig. 120, but with portant difference that it would be shifted more or less to ght, its maxima and minima being less in value and occurring han would be the case if the armature had little or no self- tion. Owing to the fact that it is not possible to construct ctical armature with as little self-induction as the simple gle, or to make its active limbs cut the lines of force of a m field in such a regular manner as is done by our experi- l rectangle, we do not in practice obtain a perfect sine curve e curve of potentials of any armature, but only an approxima- thereto.

e shall presently be better able to consider the reaction on d in connection with a different type of armature, but we here remark that it is one of the most important points to be e in mind in deciding how a more powerful and efficient ine can be obtained. Now, the electro-motive force may be sed in several ways.

By increasing the speed of rotation.

By increasing the number of turns of wire in the armature, reasing the number of active limbs joined in series, which lines of force. This method, as already pointed out, adds to the resistance, but also to the self induction of the

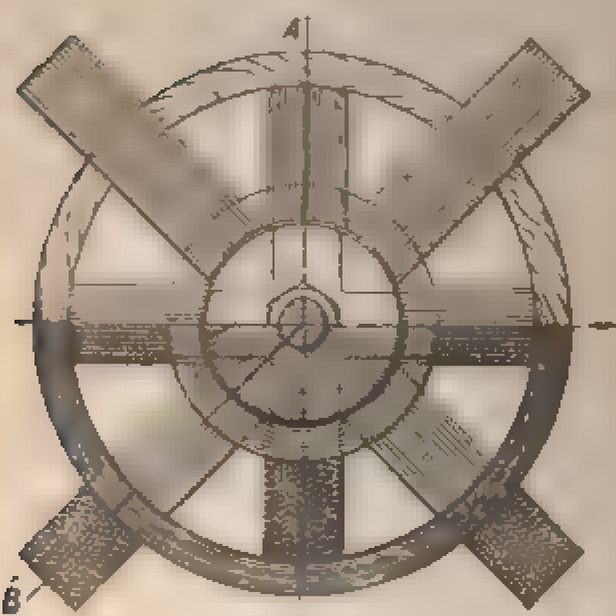
increasing the area of the [illegible]ture coils, or by making massive, for in [illegible] the number of lines of the coil is, within [illegible] increased

increasing the strength [illegible]

method is [illegible] objections, and it

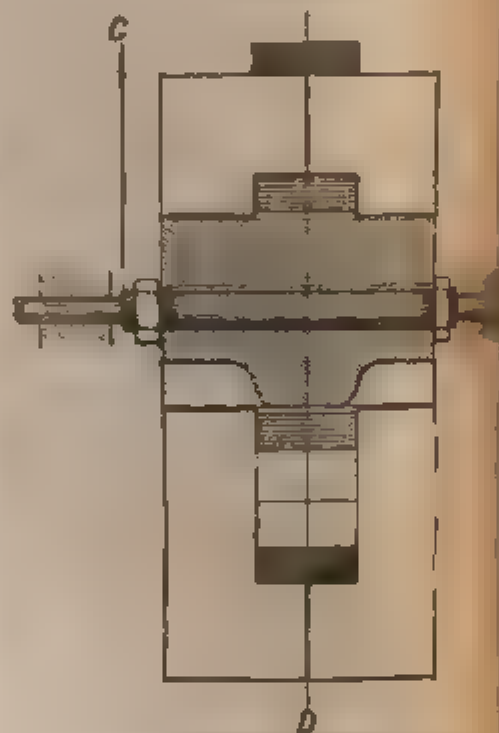
of 128, however, the keeper completes the various magnetic circuits in such a manner that most of the lines of force extend round both coils. These two alternate conditions succeed one another rapidly as the keeper continuously revolves. As the lines of force are rapidly carried backward and forward past the armature coil, they generate therein the desired currents, but they also give rise to eddy currents in the masses of iron through which

Fig. 128.



Section through C D.

Fig. 129.



Section through A B

they are projected. The direction in which these eddy currents would be set up is parallel to the currents in the armature coil, and therefore the masses of iron should be laminated so as to give discontinuity in this direction, while continuity is retained in the path of the lines of force. Consequently the iron is built up of a number of thin U-shaped sheets, insulated and bolted together.

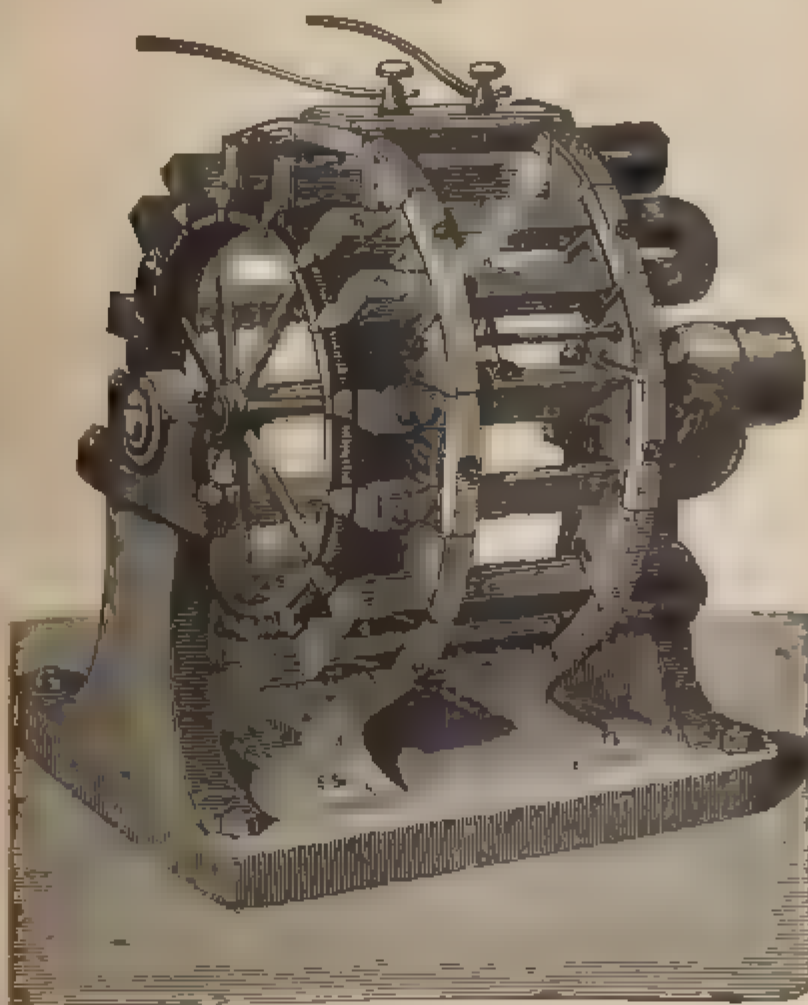
Machines in which steel magnets are employed for producing the field are often called magneto-electric generators, and are sometimes regarded as a class altogether distinct from machines in which the field is developed by one or more electro-magnets, but such a distinction is altogether arbitrary.

The best and most useful form of so-called magneto dynamos

…t of De Meritens, which is extensively employed for lighthouse …oses. A general view of a simple form of this machine is …n in fig. 130.

…he armature consists of a series of sixteen coils fixed round …eriphery of a wheel of brass or other non-magnetic material.

Fig. 130.

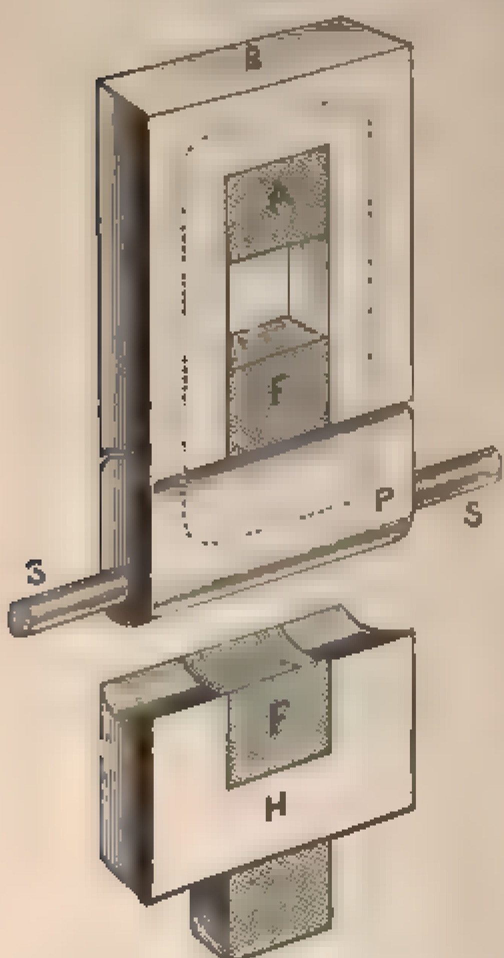


…method of constructing and fixing the coils is shown in fig. … one coil and a portion of the rim of the wheel being in …on. A flat core of soft iron (composed in the more recently … machines of eighty pieces of soft sheet iron one millimetre … and stamped out to shape) is provided with rather large …pieces, and has wound over it about $1\frac{1}{2}$ pounds of copper … Each coil is distinct from the others, the cores of two …ent coils being magnetically insulated (at x y, fig. 132) by … strip of copper. The wheel or frame to which the coils

causes many of the lines of force at one moment to em
armature and field coils, and at the next moment to
the field coil only; and as, during their movement
position to the other, they cut the armature coil t
alternating currents are induced in that coil.

The principle may be more easily grasped by a consi
the arrangement illustrated in fig. 127, in which F F sho
coil in section at two
opposite extremities of
and A A show sectio
two similar points of th
coil. B is a mass of i
embraces both the ar
field coils, while H i
equal in cross-section
shorter limbs, which en
field coil only, the ar
being placed outside
P is a keeper carried b
S, which can be rotat
the shaft being at the
the two circular coils, F
If a powerful curre
through the field coil
number of lines of fo
developed, and their ar
will largely depend up
pieces, H and B, but r
cially upon the positi
keeper P with respect t

Fig. 127.



When P is situated as shown in the figure it forms
almost complete magnetic circuit of low permeability
coils A and F, and nearly the whole of the lines generat
field coil in the vicinity will embrace the armature. In
into this position (shown by the dotted line), the lin
armature coil transversely from the inner side, and giv
current, depending in E.M.F. upon the number of line
rapidity with which their position is changed. When

oved away there is a considerable air gap, offering a high mag- resistance at the ends of the limbs of B, and consequently of the lines of force collapse upon the coil F, cutting the ture from the outside and generating an E.M.F. in the opposite tion. Not only is the magnetic resistance of the path round the coils made greater, but as P rotates it reaches a position where it as a keeper to the iron piece H, which embraces the field coil so that an almost complete magnetic circuit is then formed d the field coil, and nearly the whole of the lines of force pass gh H and P and very few extend round A. Therefore, if the er P is rapidly rotated the armature coil will be cut by a ber of lines of force as they take up new positions, first out- and then inside it. It is evident, however, that it would not ossible to make all the lines of force developed by the field ake either the one path or the other, many of those surround- e coil at a distance from the iron being but little affected by ovement of the keeper, but in designing an actual machine would be taken to so dispose the iron that most of the lines ce would be influenced.

n Mr. Mordey's machine there are four iron pieces similar to bracing both armature and field coils, placed 90° from each as shown in fig. 128. Between these are placed four shorter s similar to H, outside the field but inside the armature wire. he lower half of fig. 128 is shown in section; fig. 129 is also ction, the upper half from A to the centre of the shaft, and ower half from the centre of the shaft to B, so as to obtain a n through a short and a long iron limb. The mass of cast- which plays the part of a keeper may be described as a der having four deep sector shaped notches cut at each end. ewed end-on, a section near one extremity would be in the of a cross, while a section through the middle would be lar. In the figures each arm of the cross is shown as forming per to one of the smaller iron pieces embracing the inner or coil only, and consequently few of the lines developed by the coil extend round the armature coil. In the lower part of 129 the deep notches are opposite the iron pieces which ce both coils, forming a great break in the magnetic circuit, this is also shown in fig. 128. On rotating through an angle

current in the external circuit. The whole of the coils in fig. 130 being joined together in series, the total E.M.F. developed is sixteen times that developed in one of the coils. In the more recent form of this machine there are five armature rings, each with its sixteen coils and eight compound magnets. The latter are, for very apparent mechanical reasons, fixed radially instead of longitudinally, and they have a total weight of about one ton. The eighty coils are divided into two circuits which are brought to four collecting rings mounted in pairs on an insulating bush fixed on the principal shaft of the machine and, therefore, revolving with it. This type is almost exclusively employed for lighthouse purposes, and its E.M.F. varies almost directly with the speed of rotation. It is unusually strong in design, the parts being also fixed together in such a manner as to permit of their being, when defective or injured, very easily removed for renewal or repair.

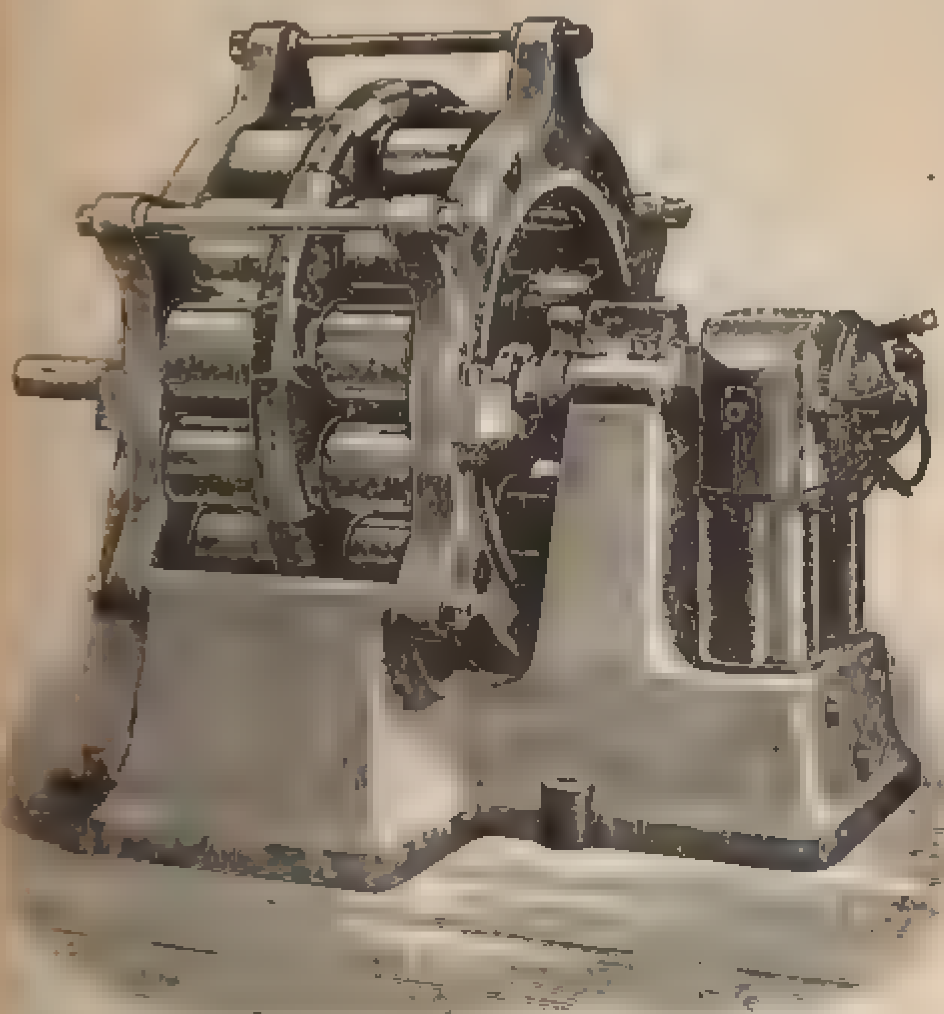
It has been pointed out that the best means available for increasing the E.M.F. and therefore, also, the strength of the current yielded by a machine, is to increase the strength of the field. Now there is a limit, which is soon reached, to the field obtainable with permanent steel magnets even if built up of thin sections, because the maximum number of lines of force which can be urged through steel is comparatively low, and even then only a portion of this number can be permanently retained, whereas with good soft iron a far greater number can be forced through. If the lines of force are produced by a current circulating in a coil of wire enveloping the iron, the question of retentivity does not arise. Consequently, to develop a given amount of power, a machine in which the field is produced by electro-magnets is considerably smaller than one in which steel magnets are employed.

Primary batteries might be, and in fact were at one time, used to furnish the current for the purpose of exciting the field-magnets, but it is far more economical and advantageous to obtain this current by means of a small dynamo. This auxiliary machine, which we will for the present refer to as the exciter, must be able to excite itself and to yield a current continuous in direction. Descriptions of many such dynamos will be found in the following chapters.

We can scarcely do better, in commencing a study of the

modern forms of alternating machines, than describe one which would appear to follow as a natural evolution of the De Meritens. Such a machine, excellent alike in its mechanical and its electrical details, is the one designed by Mr. Gisbert Kapp, and illustrated in fig. 134, which also shows the small exciter mounted on an extension of the main bed-plate, its armature being also fixed on

FIG. 134.



the main shaft. The field is produced by two crowns of short cylindrical electro-magnets, the cores of which are of wrought iron 3 inches in diameter, fixed at one end into cast-iron yoke rings, and provided at their inner ends with rectangular pole-faces, between which the armature revolves. There are twenty-eight of these magnets, fourteen in each crown. Each magnet is wound with 186 turns of thick insulated copper wire, the whole of the

are attached is furnished with a number of ... ends of the pole pieces of the cores are ... and, being provided with semi-cylindrical ... dimensions, the whole are firmly fastened together ... is important to notice that the extensions of the ... air space between the poles of the permanent ... cores ... and ... duce ... tion ... possib... of ... throug... conse... gener... maxim... E.M.F.

Fig. 131.

Th... duced ... of eigh... steel ... horizo... the armature ring, by means of a brass framework ... surfaces of the magnets are provided with small ... pieces, so that the coils in revolving pass as clos... magnets as possible. The magnets are disposed ... the ring, the coils passing, therefore, north and sou... nately.

Th... between the limbs of each magne... equal ... een the op... les of the adj... and ... ing ... the length ...

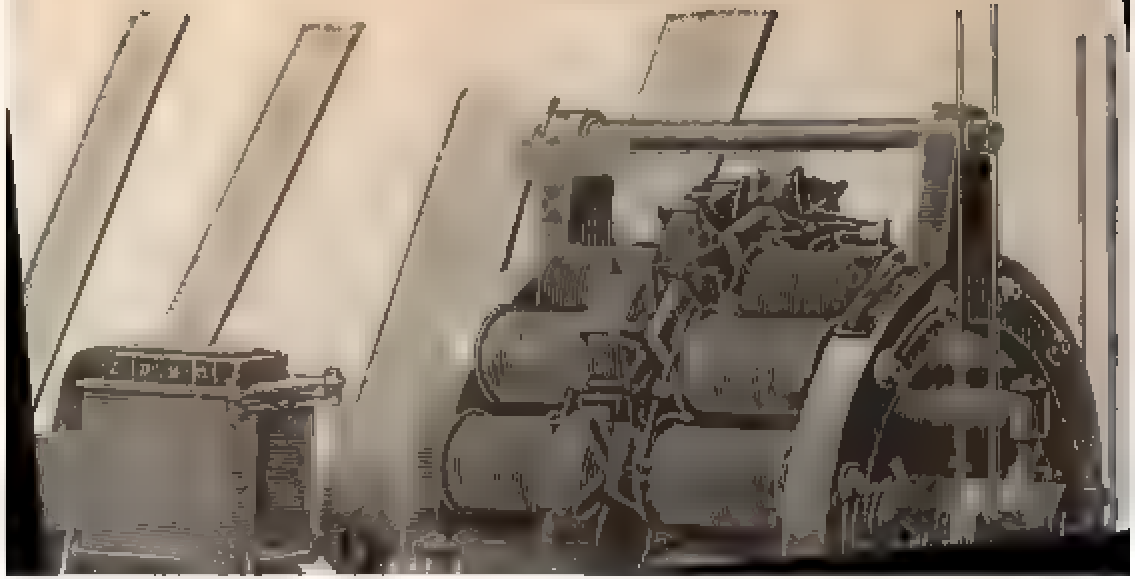
bolting the yoke-rings to it and to each other is clearly shown in the illustration.

When all the coils are joined in series, the total E.M.F. at the collecting brushes is equal to that developed by one coil multiplied by the number of coils, but occasionally, in such machines, a lower E.M.F. with a heavier current is desired, and then the coils are joined in parallel, either in two sets, or as may be required. An equal E.M.F. might, of course, be obtained with fewer coils and pole-pieces, provided the number of lines cut in the same time and the number of convolutions in series is made the same; but the great advantage accruing to the use of a large number of pole-pieces and coils is that a rapidly alternating current can be obtained without rotating the armature at an enormous speed, and so introducing mechanical difficulties.

It ought perhaps to be explained here that the current, or rather currents, resulting from one complete rotation of a coil in a simple field, which may be represented by the curve A C E F in fig. 120, is called an 'alternation,' and any similar pair of currents developed by any armature with any field is also called an alternation. In estimating the rapidity with which a current is reversed, it is better to speak of the number of such alternations which take place in a second, rather than the number of reversals. The majority of the machines at present in use work at from 80 to 100 alternations per second, and to obtain the latter number a single coil in a single field would have to be driven at 6,000 revolutions a minute. But although a rapidly alternating current can be easily obtained with a large number of pole pieces, a disadvantage results from the fact that these pole-pieces alternate in polarity all round each crown. Each pole-piece is flanked on either side by others of opposite polarity, and a very large percentage of the lines of force leak across between adjacent limbs, instead of passing through the armature core, and are wasted, since they cannot be cut by the conductor. This defect also exists in the two machines next to be described, where the armature contains no iron.

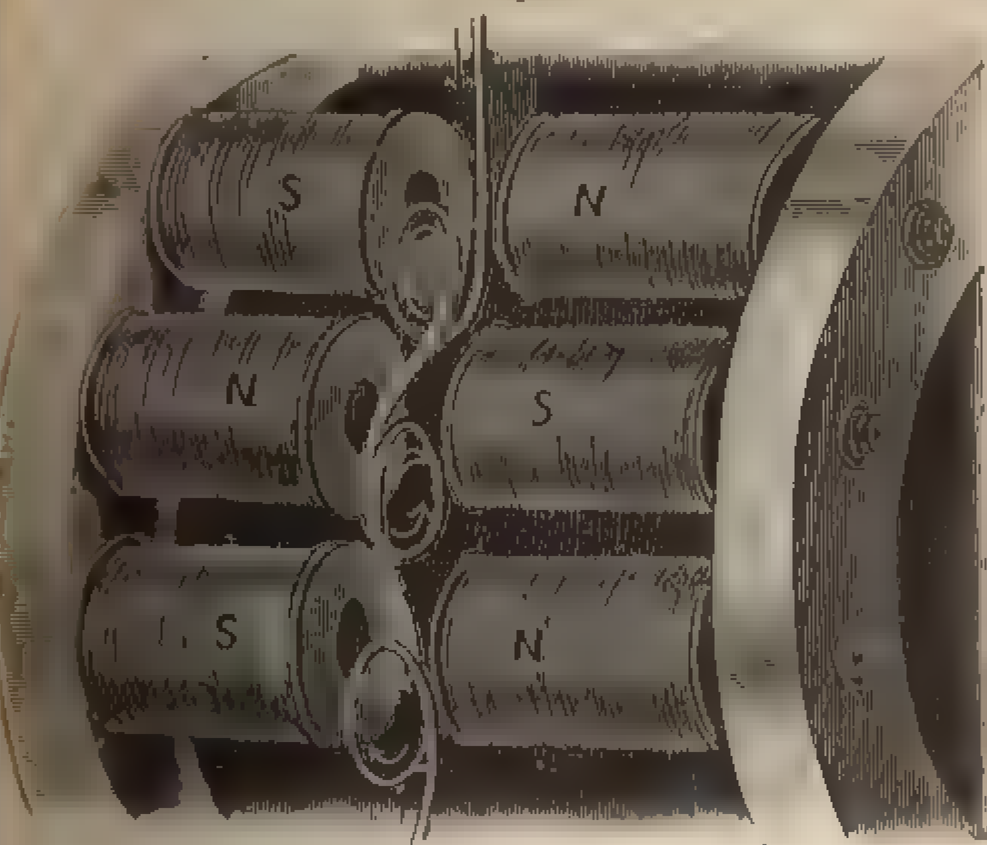
The form of alternating current dynamo constructed by Siemens is illustrated, together with its exciter, which is driven, independently, from the main shaft, in fig. 135. The field magnets present an appearance similar to that of those in the Kapp machine, consist-

FIG. 125



larity. The arrangement is clearly indicated in fig. 136, which ows three pairs of magnets and three ideal armature coils, and it ll be evident that, with this disposition, the lines of force pass om pole to pole, straight across the armature space. The plane the armature coils is coincident with the plane of rotation, so that e coils, in rotating, cut through a series of powerful fields with e lines of force alternating in direction. As through any adjacent ir of coils the direction of the lines of force is opposite, it is

FIG. 136.



cessary, in order to prevent the current induced in one coil neutral- ng that induced in the other, either to make the connections as the case of the De Meritens (fig. 133), or to wind the bobbins as ght and left handed helices alternately, after the manner shown fig. 136 The number of armature coils being the same as the mber of fields, it follows that all these coils are, at any particular oment, equally active Referring to fig. 136, in which the rection of rotation is left handed, it will be seen that the coils e just leaving the pole pieces, and currents are being gene-

rated in the directions indicated by the small arrows. The E.M.F. increases until the coils arrive at positions midway between the pole pieces, where it is a maximum, because at that moment the forward half of each coil is cutting lines of force in one direction and the rear half in the other direction. And the induced currents, flowing outwards in one half and inwards in the other, coincide in direction round the coil. Every line of force then cut by the coil is being usefully employed. When this middle position is passed, the number of lines cut by the front half increases, while the number cut by the rear half decreases, and this continues until both halves of the coil are cutting lines of force which are all in one direction. Consequently, an opposing E.M.F. is induced in the rear half, the value of which increases until the coil is exactly opposite the pole pieces, when both halves will be cutting an equal number of lines of force, which are all in the same direction; whence equal and opposite E.M.F.'s will be induced in the two halves of the coil, thus neutralising each other. At this point, then, the reversal in the direction of the current takes place, for, on passing forward, the front half of each coil is cutting less, instead of more, lines of force than the rear half. The number of alternations in each revolution corresponds, therefore, with the number of coils, or, what is the same thing, with the number of fields.

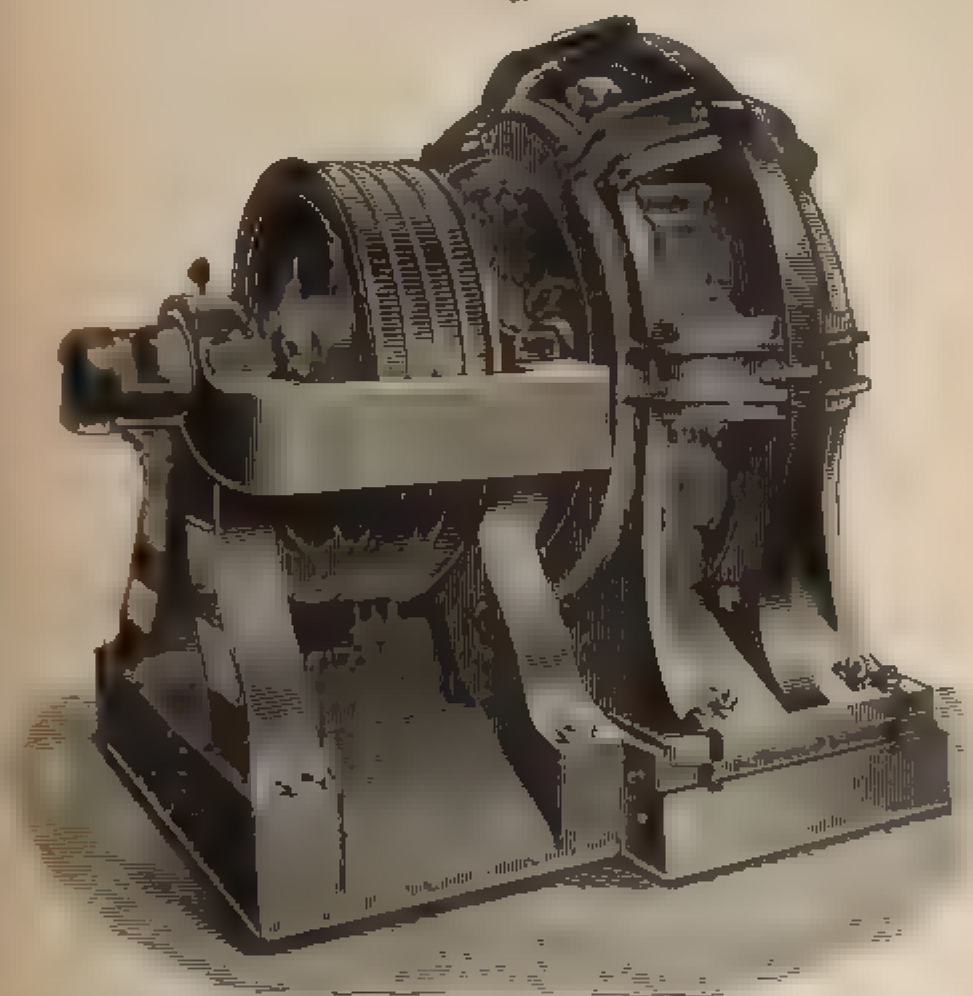
In practice, the machine is built up on a cast-iron bed-plate, to which are securely fixed two circular frames, united and held in position by a stout iron stay. An equal and even number of electro-magnets is fixed to each frame, the cores being turned down so as to fit into holes drilled through the frames. These ends are likewise tapped, and, nuts being screwed on on the outside, the electro-magnets are fixed firmly in position. The inner ends of the cores are furnished with radial pole-pieces, to concentrate the fields and increase the number of lines of force passing through the rotating armature coils.

The armature is fitted up by attaching the coils, which are wound over wooden cores, round the circumference of a disc or wheel which is mounted on the shaft. The coils, instead of being circular, like those in fig. 136, are pear shaped.

A general view of the latest form of machine designed by Mr.

S. Z. de Ferranti, is given in fig. 137, the particular one illustrated being constructed to develop 150 electrical horse power. The field-magnets are similar in principle to those in the Siemens Alternator, and consist of two sets of electro-magnets, attached to massive iron rings forming the yokes, the magnetisation of the pole-pieces round each ring being alternately north and south, and the facing pole-pieces also of opposite polarity, so as to develop a series of very power-

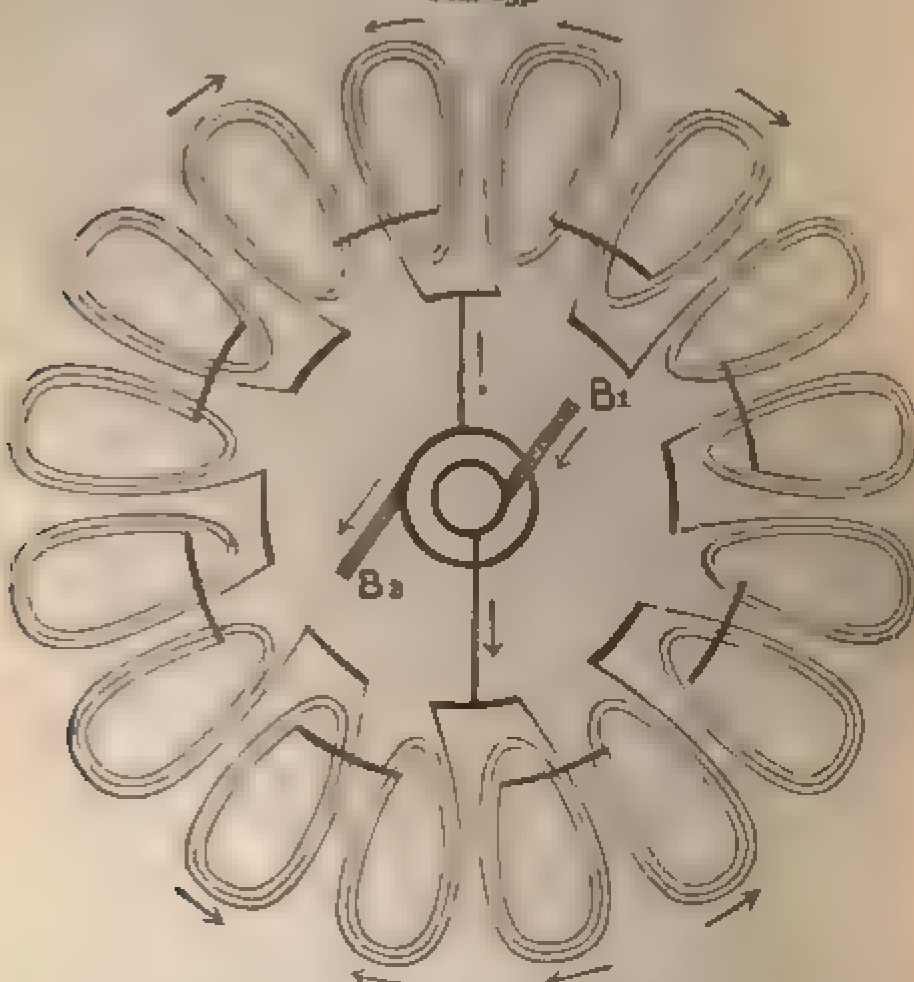
FIG. 137



ful fields, alternating in direction. The framework carrying each crown, or ring, of field-magnets is divided vertically into two halves, which, on being unbolted, can be slid out of position in a direction at right angles to the shaft, and so afford access to the interior for cleaning or repair. It may be mentioned that in larger machines at Deptford a small steam engine is specially provided for the purpose of withdrawing the field magnets when necessary.

them will be instructive. The mean diameter of the armature is 7 feet, and it comprises 40 coils, joined up in two sets of 20. The copper ribbon is 12·5 millimetres wide, and 0·75 millimetre in thickness, twenty-five turns being wound over a core of brass (insulated with asbestos) to form each coil, the convolutions being insulated by means of a continuous strip of fibre, 0·5 millimetre thick, wound on with the copper. The inner end of each coil is

FIG. 139.

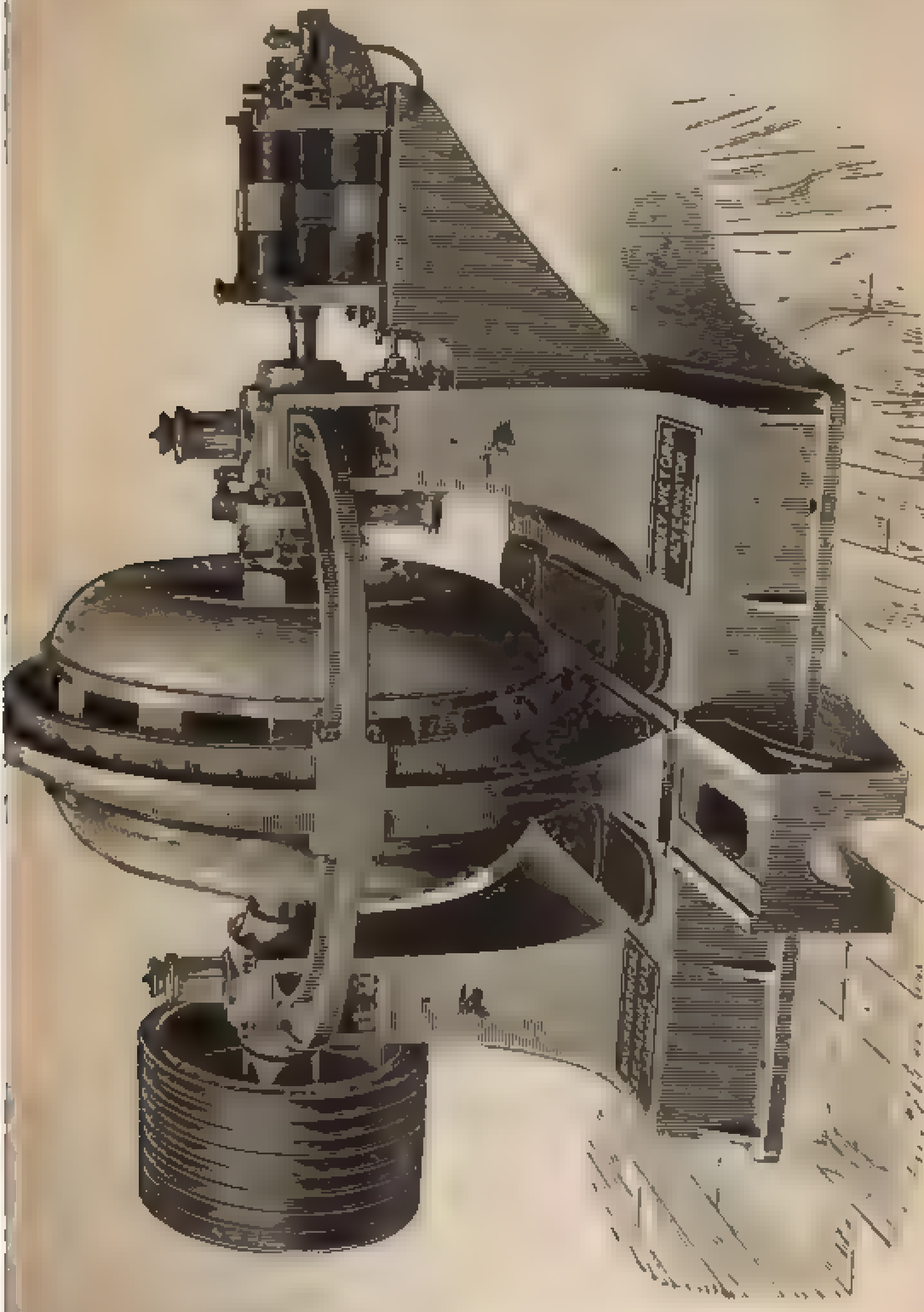


connected to the brass core, these cores being also electrically connected together in pairs, as indicated in fig. 139. In a somewhat similar manner the outer ends of the coils are connected together in pairs through the supporting framework.

The peripheral velocity of the armature is 6,050 feet per minute, and, manifestly, special attention has to be paid to the method of fixing the coils to prevent their flying out.

The external potential difference developed is 2,400 volts, but

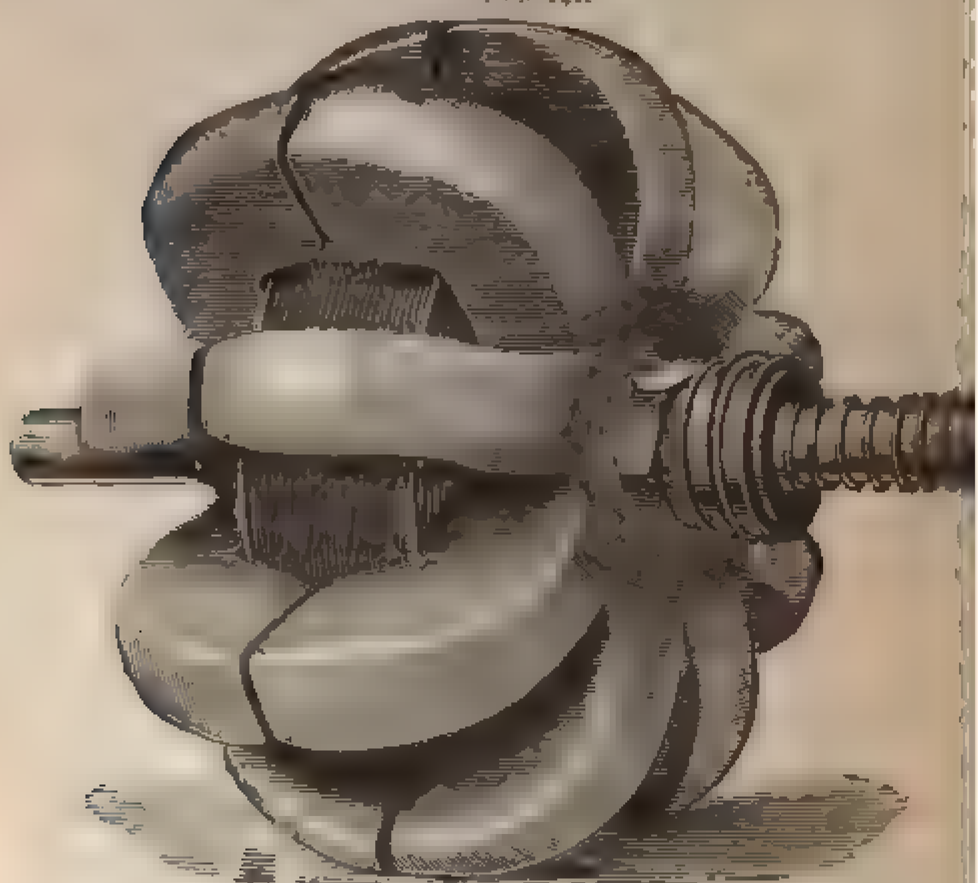
the adoption of the device shown in fig. 139 the maximum potential difference between the wires on neighbouring coils is re-



duced to 120 volts. The resistance of the armature from brush to brush is 0·176 ohm.

dispensed with, and the exciting coil, as well as the ar
might be made stationary. The core and its pole-pieces
then be the only portions revolving, and the electrical effect
be the same, but serious mechanical difficulties would a
fixing the coil. Hence, it is far preferable to attach it
rotating cylinder. The simplicity of this form of field ma
one of its great features, as a single exciting coil suffices
machine of any size, speed, or number of alternations. The
rotating field-magnet acts very efficiently as a fly-whee

Fig. 142.



ensures safety and steadiness of running, effectually neutra
within certain wide limits, any pulsations due to irregularity
stroke of the engine. Further, as the parts revolving at the hi
velocity are simply solid masses of iron of the strongest de
tion, the electrical and mechanical considerations which w
render low speed advisable do not apply here. The insula
the armature coils is also simplified, and being stationary
need only to be supported with a view to resisting the drag

The machine illustrated in fig. 140 is the latest pattern of the Mordey Alternator. In the earlier machines, copper dishes were attached outside the cast-iron claws of the field magnets, for the purpose of reducing the amount of air churning which would otherwise occasion loss of energy. The claws, in fig. 142, are shown without these dishes; in the newer form of the machine they are dispensed with, the claws being simply webbed together in the casting, when they present the appearance shown in fig. 140.

The field-magnet is excited by the current from a small Victoria direct-current dynamo, which is mounted on a bracket projecting from the main bed-plate, its shaft being coupled direct to the alternator shaft, so that the two machines are driven together.

A long thrust bearing is employed to prevent end play, since the space between the pole-faces and armature is very small and it is adjustable longitudinally, for the purpose of enabling the field magnet to be symmetrically disposed with regard to the armature. The armature terminals are placed on the upper portion of the gun metal supporting ring.

The machine, when driven at 500 revolutions per minute, is capable of developing 75,000 watts, or 100 electrical horse power at an E.M.F. of 2,000 volts. 900 watts are required for the purpose of exciting the field-magnets. On account of there being no iron in the armature, and the attention devoted to small details such as the use of German silver for the coil fittings, the waste of power due to eddy currents is very small; and this loss, added to that due to friction, which, owing to good mechanical construction, is also very low, amounts to but 5 horse-power, that being the power required to drive the machine at full speed on open circuit (or when the armature is disconnected), the field-magnets being excited to their maximum.

In many cases the output demanded from a dynamo varies considerably at different times. For instance, twice as much power may be required to supply lamps at one time as at another.

It is not economical to use one large machine, capable of meeting the maximum demand, and run it to give a small output at other times, but, fortunately, it is possible to join up two (or even more) alternating current dynamos so as to feed the same

rcuit simultaneously when required, switching out and stopping e when the other is able to meet the low demand.

The armatures must not be joined up in series, but in parallel, d the machines may be driven by belts from the same shafting, , if necessary, from independent engines running at about equal eeds. In practice the latter course is usually adopted, since it bad economy to employ a large engine to develop the power quired by a small machine.

But parallel working is only practicable when in both machines e rates of alternation are equal, and the alternations 'co-phasal' that is, when their maximum and likewise their minimum M F.'s occur simultaneously. It is most remarkable that well-signed machines can correct each other and maintain this nchronism; but, as a most important part of the interaction pends upon the 'motor' properties of a dynamo, further con-deration of the question must be deferred until electric motors ve been dealt with.

CHAPTER IX.

DYNAMO-ELECTRIC MACHINES (DIRECT CURRENT).

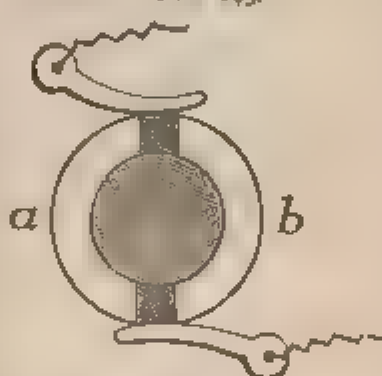
ALTHOUGH the sphere of usefulness for alternating-current dynamos has largely increased of late years, there is still a vast amount of work which such machines are, and always will be, wholly incompetent to perform. This is notably the case in connection with the deposition of metals by electricity, and in the 'charging' of secondary batteries. For these, and several other important purposes, it is essential that the current should be continuous, and flow in one direction only. It is possible to arrange matters so that all the currents generated by a dynamo shall be made to flow in one direction in the external circuit, the process being known as 'commutation,' and the part of the machine by which the alteration is effected is termed the 'commutator.' Directly this has been successfully performed, the dynamo is capable of a new and important development, for it is then possible to use all, or part of the current which is generated in the armature, for the purpose of magnetising the field magnets. The smaller auxiliary machine, which, in most of the dynamos previously described, has been employed to excite the field-magnets, can therefore be dispensed with, and the machine made 'self-exciting.'

We come then to the consideration of the means to be employed in order that the currents which are generated in alternate directions can be commutated so as to flow in one direction in *the external circuit*. Referring again to fig. 120, we remember that the *direction* of the current is unaltered (although it varies in E.M.F., and therefore also in strength) during the first half revolution of the rectangle, and that, at the end of that half revolution the reversal in direction takes place. Now, a moment's reflection will show that if, just at the end of this first half-revolution,

tions of the two brushes on their respective rings were inter-
nged, the current generated during the second half of the
lution would flow in the same direction round the external
uit as the preceding current did, because, although really gene
d in the reverse direction, it is entering the external circuit at
other end. This is the fundamental principle of commuta-
; only, instead of shifting the brushes, the change is effected
e right moment by a modification of the ring or rings against
h they press.

The simplest possible form of commutator is shown in section
g. 143. Instead of two brass rings, a single brass ring or tube
ployed, but with the difference that
split lengthways into two halves or
nents, *a b*, insulated one from the
. Each end of the coil of wire is
ected to one of these segments, and
brushes or flat springs are so situated
they press upon the divisions between
egments at the moment that the coil
the vertical position that is to say,
e position where the reversal of the
ent takes place. Just at that moment, then, the ends of the
in contact with the respective brushes are also reversed, and
esult is that when the coil is rotated uniformly, a succession
hort currents passes through the external circuit, each current
g and falling similarly, but all impelled through the external
it in the same direction.

FIG. 143.



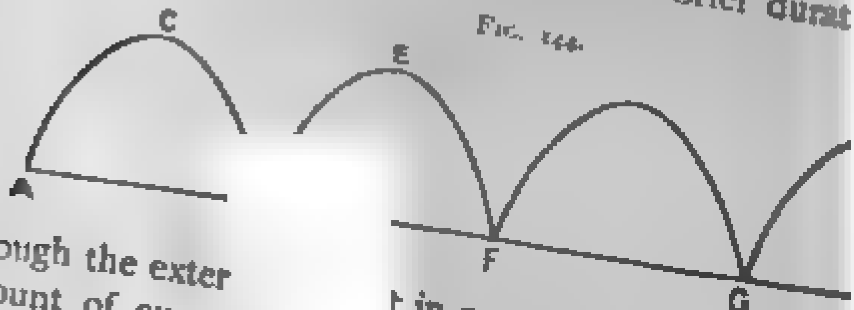
The length of the wire can easily be increased by winding it in
mber of convolutions, instead of in a single rectangle, when,
matter of course, the E.M.F. will be increased proportionately.

The variation in the E.M.F. developed by an ideal alternating-
ent dynamo is shown in fig. 120, where the line A B represents
ormal or zero potential, the curves above it indicating the gra-
rise and fall of, say, the positive potential, and those below it
pposite, or negative potential.

Fig. 144 exhibits, in a simple manner, the result of replacing
o metal rings by a split tube, or simple two part commutator.
gain indicates the zero potential, and the curve A C D the

varying potential developed during the first half-
instead of the second half developing in the ext
negative potential, it is commutated into an extern
so that a series of currents, each of brief durat

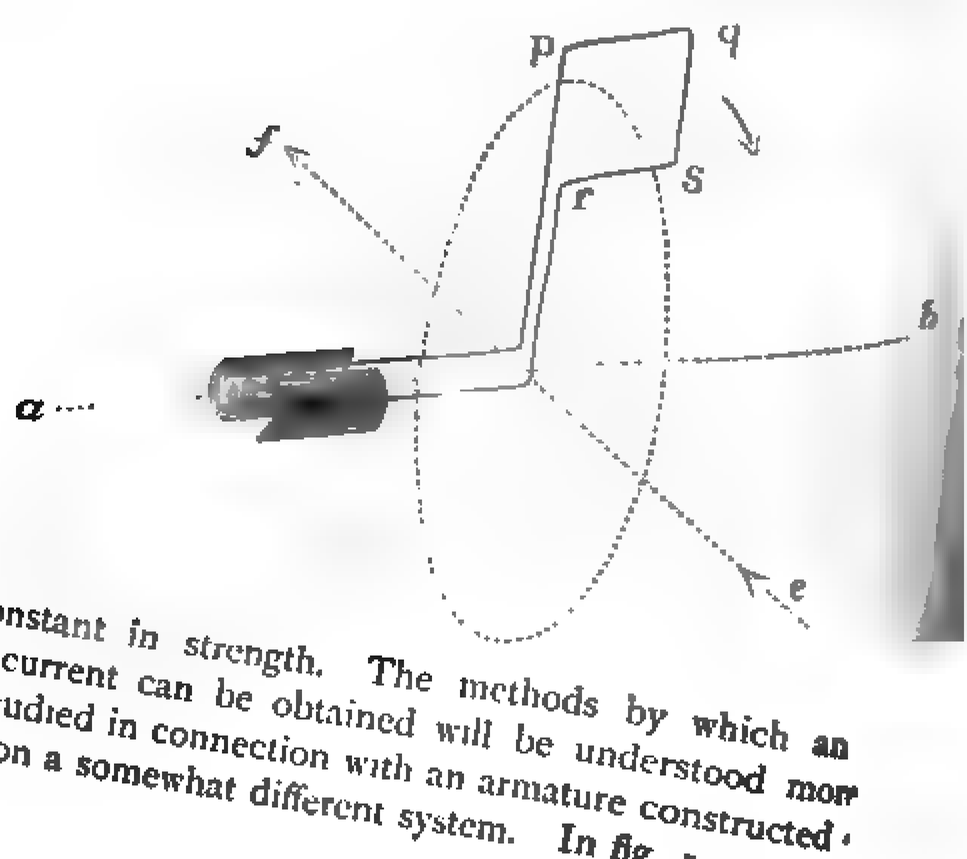
Fig. 144.



through the exter
amount of curren t in one common direction.
although its streng ed is, however, the same
maximum. lates rapidly between zero

A current varying so much in strength is, however, of
little service for many purposes as alternating currents
most cases, the current must not only be uniform in d

Fig. 145.



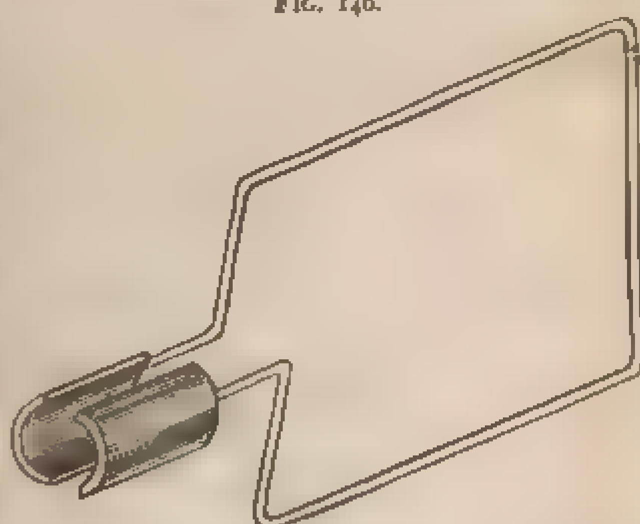
but constant in strength. The methods by which an steady current can be obtained will be understood more when studied in connection with an armature constructed wound on a somewhat different system. In fig. 145, *a b* is

the axis of rotation, and $p\,q\,r\,s$ a single loop of wire which travels round the circular path indicated by the dotted line. If we suppose the lines of force of the field to be in the direction of $e\,f$, along, or parallel to, a diameter of this circular path, then they will be cut by the coil in a manner somewhat similar to that of the rectangular coil which we have just been considering.

The movement from the vertical position through the first half-revolution produces a current which rises to a maximum when the coil has turned through an angle of 90°, and falls to zero again when the coil reaches 180°, while the current generated in the next half-revolution is exactly equal in strength, at corresponding positions, though opposite in direction; but it can be commutated in precisely the same way as in the case of the rectangular coil. The ends of the coil are connected to the metallic segments (equivalent to $a\,b$ in fig. 143) of a simple two-part commutator.

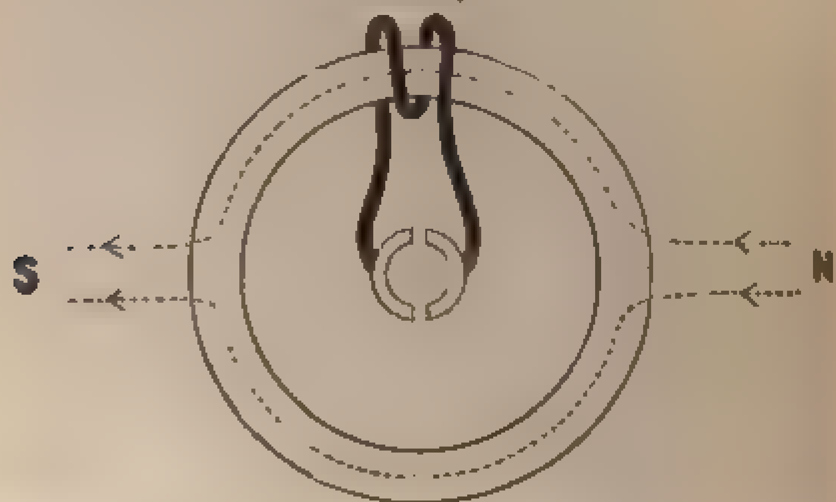
There is, however, one great difference between the two methods. No portion of the coil shown in fig. 146 acts prejudicially, although the portions connecting the horizontal limbs are always idle, inasmuch as they do not cut, but only slide, through the lines of force. But with the coil shown in fig. 145 the case is different. There are still two idle connecting lengths, $p\,r$ and $q\,s$, but the E.M.F. induced in the two horizontal limbs $p\,q$ and $r\,s$ is in the same direction in each—say from p to q and from r to s—because they always cut the lines in a similar sense, although at different rates; they therefore act in opposition to each other. But the outer limb $p\,q$ traverses a greater portion of the field and moves at a greater linear velocity than does $r\,s$, and consequently, as it cuts more lines of force, and at a greater speed, than $r\,s$, the E.M.F. generated by it is the greater, the resulting current round the coil being therefore that due to the preponderance of the E.M.F.

FIG. 146.



of the limb pq over that of rs. Now, the lines of force which the outer limb cuts in excess of those cut by the inner limb are simply those which pass through the coil when it is in the zero position, as in fig. 145, and it is evident that if the field is uniform and the coil comparatively small the lines thus embraced will be very few indeed, and the use of iron to increase their number immediately

FIG. 147.



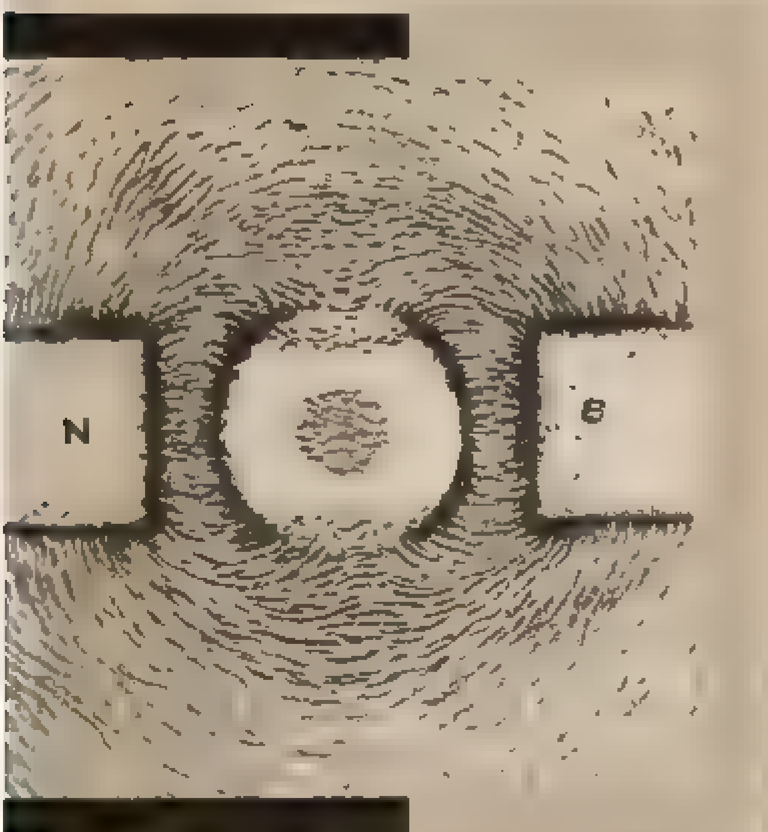
suggests itself. It is most advantageous to make the iron in the form of a ring, as shown in fig. 147, and cause it to rotate with the coil.

In fig. 148 is illustrated the effect of placing a ring of iron in a magnetic field. The apparatus employed to obtain this figure consisted of a quantity of thin soft iron wire wound into a ring, and placed between the opposite poles of two powerful bar magnets, a sheet of paper being laid over them, and iron filings sprinkled upon it. The spaces free from filings represent those places where the permeability of the iron is sufficiently high to prevent any appreciable number of lines of force extending above the paper so as to give direction to the filings. The manner in which the lines converge into the ring should be noted, and it will also be observed that at two places, on a diameter at right angles with the lines, the magnetic effect above the paper is considerable. The reason for this is that the greatest number of lines pass through the iron at these points, and the permeability is sufficiently reduced to allow some lines to leak above the paper. Comparatively few lines pass diametrically across the ring, about half of them going

upper and half through the lower part of it, and inner limb of the coil (fig. 147) cuts but very few resulting E.M.F. is practically that developed by the one.

se illustrated in fig. 147 only one-half of the total nes of force urged through the iron can, at any one ough the coil, and some device is therefore necessary

FIG. 148

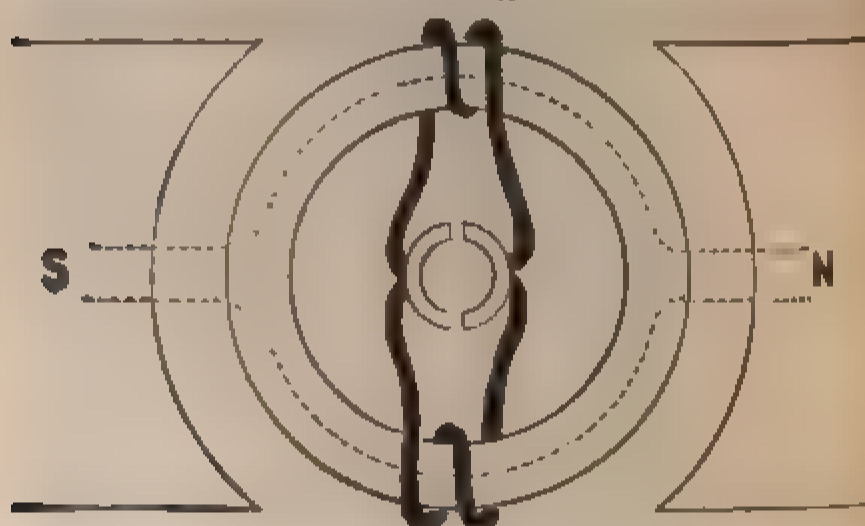


other half to be utilised. Now, since the induced same in any given position after the coil has passed s in the corresponding position after it had passed t, it is clear that a second coil might with advantage the opposite extremity of a diameter of the circular d by the coil. We will assume that the limbs on the y alone are active, and it will be seen that if the nt flows from front to back in the outer limb of the will flow from back to front in the outer limb of the ause these limbs always cut the lines from opposite

sides, viz. one from above and the other from below. The E.M.F. is, however, at any moment equal in each, and, by joining the ends which are at a positive potential to one segment and the ends which are at a negative potential to the other segment, both coils are made to deliver their currents in the same direction to the external circuit.

Fig. 149 illustrates the arrangement for employing two such coils; they are similarly wound (right-handedly in this case), and

Fig. 149.

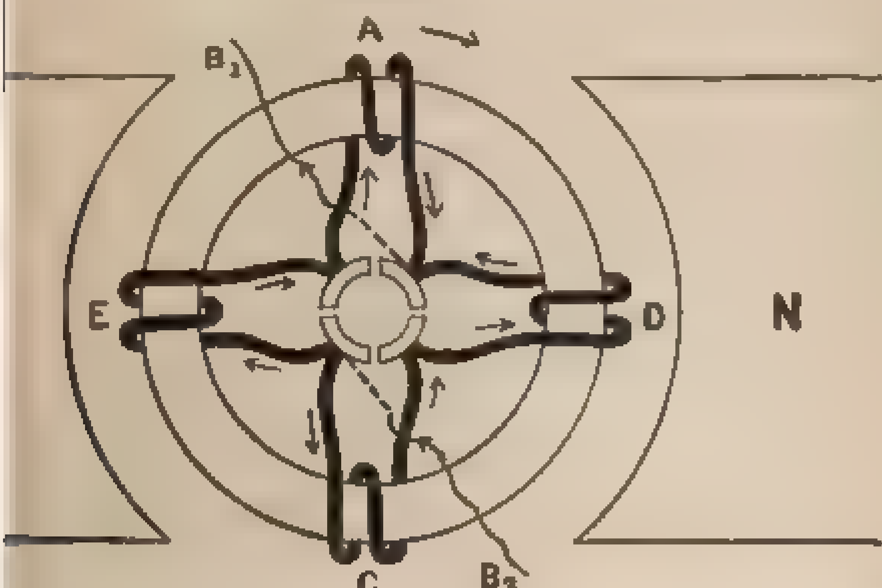


their *adjacent* ends are joined to the same section of the commutator. Now, as they are at opposite extremities of a diameter they pass at every moment through parts of the field where they act with equal effect, and therefore, as already pointed out, the E.M.F. will be the same at the extremities of each coil. Since the ends of the two coils, which are at the same E.M.F., are joined to the same segment of the commutator, the E.M.F. due to both coils is only the same as that produced by one of them. It is, in fact, an exactly analogous case to that of joining two primary cells of equal E.M.F., in parallel. There is also the similar advantage here that because the coils are joined in parallel the internal resistance between the two segments is only half that of one coil, and, as we have seen, any arrangement that so reduces the internal resistance of a current generator is sometimes very valuable. By increasing the number of turns in the coils we increase the E.M.F. because a greater number of conductors in series, round the p

usefully cutting lines of force; but, of course, the ust be exactly the same in each coil. In figs. 147 and re two active conductors to each coil.

now in a position to proceed with the consideration of for making the short fluctuating currents depicted in pproach more nearly to a continuous steady current. t currents are at a minimum when the coils are at right he lines of force, or at that point where the reversal of d current takes place, and it is evident that if a second ls be placed at right angles to this existing pair, as in ey will always lie parallel to the lines of force, or be in

Fig. 150.



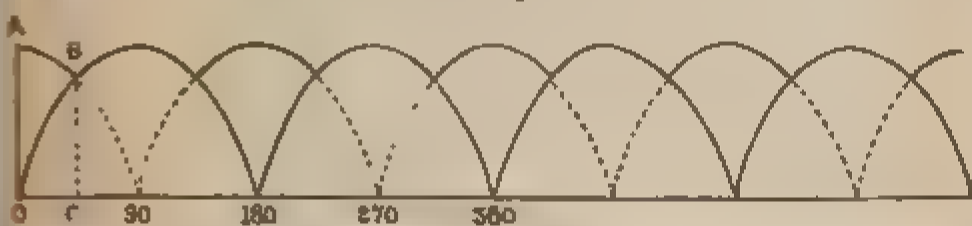
n of best action, just at the moment when the first pair t idle. But it now becomes necessary to divide the or into four parts, all the coils being, of course, similarly d the adjacent ends of adjacent pairs connected to the ent of the commutator. When only two segments are the brushes, as we have observed, are placed so that ns of the commutator pass them just at the moment oils are at right angles to the lines of force, and when lmost idle. In the present case, with four coils, the ust also be placed so that the division between each ments on the commutator passes a brush when the coil to that pair of segments is in the position of least

coils would be in the direction i
resulting current could be led fro
circuit by the upper brush B_1, ente
lower brush B_2. The two horizon
tion of greatest activity, while the
idle, and merely serve to conduc
active coils to that segment of the
touching. A moment later A and
current in the opposite direction to
but as by that time they will have
site ends will be in contact with th
tion of the current in the external
When the plane of each coil make
of force, they are equally active, a
twice that which is at that moment

The resulting E.M.F., due to t
instead of the single pair of coils, is
before, we must determine at what
is at a maximum and where it bec
(fig. 144) illustrates the variation c
one pair of coils, and as, when thi
second pair of coils is lowest an

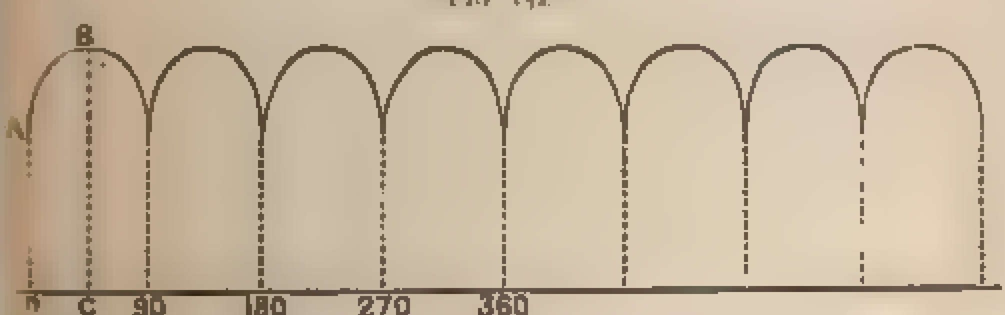
shes is at its lowest value, and the length of this line O A deter-
es the lowest point on the curve which we desire to construct.
nediately after this point is passed both pairs are acting
ether, the activity of one increasing and that of the other

FIG. 151.



reasing. At a certain stage they will be acting with exactly
ual effect, and this stage is indicated by the intersection in B
the two curves; it occurs when each coil makes an angle of
with the lines of force. To obtain, therefore, the resulting
M.F. at the brushes, we must add together these two equal
M.F.'s; consequently, twice the length of the line C B must be
en as the height of this the highest point in the new curve.
hen the coils have rotated through another 45°, one pair is
ain idle and the other at its maximum activity, so that we again
ch the lowest point of the curve. The curve so constructed is
own in fig. 152, and indicates the manner in which the total

FIG. 152.



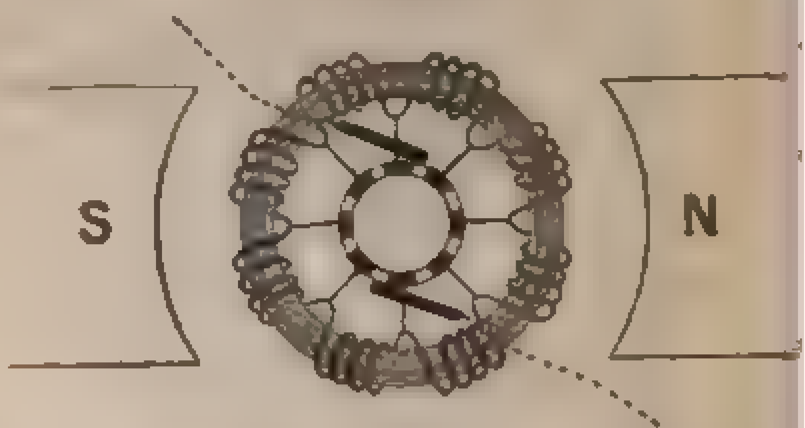
M.F. at the commutator brushes fluctuates when the armature
nsists of two pairs of coils arranged as in fig. 150. The resulting
rrent will also fluctuate similarly, depending in strength upon
e gross resistance in the circuit.

A little reflection will make it obvious that the variation in the
M.F. can be further diminished by the employment of a yet
eater number of pairs of coils in the armature, providing that

they are placed so that they each come into the positio
action at the moment when the resulting E.M.F., with
individual aid, would be at a minimum.

For instance, a coil might be placed exactly midway
each of those wound on the armature shown in fig. 15
armature would then consist of eight coils in four pairs
commutator of eight bars or segments (fig. 153). The

Fig. 153.



from such an armature would be far more steady than
the four coil armature; in fact, it may be stated generally
greater the number of coils composing the armature, the
fluctuation of the current. Of course there is a practical
the number of coils; for instance, the commutator with
of armature must have as many segments as the arm
single coils, and its construction and the making of the
connections would be difficult and expensive if the num
excessively increased.

It will be observed that in fig. 153 the whole arm
ductor is wound continuously round the core; it is divi
sections having four convolutions each, and a connecti
led from the junction of every two adjacent sections to th
segment of the commutator. The result is of course the
if the ends of each section were brought direct to the co
segment, while the actual length of the armature condu
therefore the resistance, is slightly reduced. The black
of the circle represent the metallic segments, the whi
between them indicating the insulating material.

In order to increase the E.M.F. developed in a given

speed, we must increase the number of conductors on the periphery of the armature, which can be done by adding to mber of convolutions, although this also increases the in-resistance. In the armature illustrated there are thirty-two portions of the wire round the whole external periphery, but y are joined up in two sets in parallel, the total E.M.F. is xteen times that of one active portion.

we know the number of active conductors joined in series e number of lines of force which they cut per second, it is calculate the resulting E.M.F. The E.M.F. developed by rticular conductor moving circularly in a uniform field varies ts position, and is, as we have seen (Chapter VIII.), pro-nal to the cosine of the angle which the plane of the coil of it forms a part makes with the lines of force; or to the sine angle through which the coil has turned from its position t angles to the lines of force. But we need not now trouble ves with this consideration, for, in a symmetrically con-d armature of many convolutions, the place of each con-t as it moves to a position of greater or less activity is iately filled by another, and the total E.M.F. remains un-. Since each active length undergoes precisely the same ve effects, the average E.M.F. induced in each is the same, e total E.M.F. will be equal to the number of active con-s round one-half of the armature multiplied by the average developed by one of them during half a revolution.

pposing the armature to consist of forty-eight convolutions e E.M.F. developed by one of the active limbs to be 2 volts, he whole E.M.F. would be $2 \times 24 = 48$ volts.

e average E.M.F. developed by each active conductor de-upon the speed at which it moves, and the number of lines it; in fact, we have seen that if a wire, one centimetre long, ed at a velocity of one centimetre per second transversely a field of unit strength (that is, a field having one line of per square centimetre), then the resulting E.M.F. will be o one C.G.S. unit. This unit being so very small, the volt for practical use, having a value 10^8 or 100,000,000 times the C.G.S. unit. So that after calculating E.M.F. in C.G.S. e result must be divided by 10^8 to obtain the E.M.F. in volts.

cut 32,000 lines per second and g
force of 32,000 C.G.S. units. An
in series, the total average E.M.F.
be $16 \times 32{,}000 = 512{,}000$ C.G.S. u

$$\frac{512{,}000}{10^8} = \cdot 005$$

If the armature made ten revoluti
be ten times greater (i.e. 0·05
would now cut ten times the numb

In fact we may say that the
armature of this description is equ

$$N \times \frac{p}{2} \times 2n, \text{ that is, }$$

or average E =

where N is the total number of li
armature core; P the total numb
round the periphery, and $\frac{P}{2}$, there
the number of revolutions per s
number of times per second whic
by each conductor.

The E.M.F. obtained in the l
low because

The above is a fair example of what obtains in actual practice, and the student will readily perceive that it is necessary for the quantity of iron in the armature core to be considerable, otherwise with such a large number of lines of force the magnetic induction through it (that is, the number of lines per square centimetre) would be abnormally high. We know that the permeability of iron decreases rapidly when the induction through it exceeds a certain amount, and then a large number of the lines leak diametrically across the ring instead of taking the path indicated in Fig. 149, many of them passing across the steel driving shaft, the permeability of which may be nearly equal to that of the 'saturated' iron.

Now, as these lines of force thus leaking across the ring are cut by the inner portions of the conductor (equivalent to *r s* in Fig. 145) and act prejudicially, inasmuch as the E.M.F. generated by the inner wires in cutting them is reverse to the main E.M.F., it is evidently inadvisable to endeavour to push the induction too far. As a rule the limit is from 16,000 to 18,000 lines per square centimetre, and if more lines through the core are needed, either the area must be increased or iron of higher permeability employed. The former necessarily entails a greater length of conductor. It is evident that in an armature of the type we are considering, the iron of which the core is made should be of the highest possible permeability, while the quantity of iron or steel used inside the ring should be as small as possible to minimise the tendency to cross leakage. This latter consideration implies that iron should [illegible] the purpose of mechanically connecting the [illegible] -metal or some other non-

[illegible] ciple was constructed by [illegible] until the [illegible] features [illegible] form by G[illegible]

[illegible] amme [illegible] coils [illegible] iron wire [illegible] ntity [illegible] own [illegible] wire [illegible] ted [illegible] ng

the same, and their adjacent ends connected together. The commutator segments consist of a corresponding number of brass angle-pieces, *m n*, which are fixed against the wooden boss, *a*, carried on the driving shaft.

The junction of every two adjacent coils is connected to one of the commutator segments, as shown, and two flat brushes of copper wire are pressed against the projecting ends of the segments, and serve to deliver the current to the external circuit. The latest forms of this armature, although identical in principle, are far superior from a mechanical point of view; in fact, the armature here illustrated would fly to pieces if subjected to the stresses which occur in a modern machine.

FIG. 154.

It is necessary that the commutator bars should be firmly held in position, that the wire should be bound or by some means fixed so as to prevent its being shifted, and that the core and with it the coils should be firmly secured to the driving shaft. As far as possible it will be shown, in describing the best types of machines, how well these points are attended to in practice. Especial care must be taken to prevent the generation of eddy currents in the core, and this was the reason why Gramme used rather fine wire instead of a solid ring. We have previously remarked that the E.M.F. which gives rise to these eddy currents is very low (although the current strength may be considerable, because a large mass of metal offers little resistance), and that, therefore, the merest film of insulation between neighbouring wires of the core is sufficient. Except in special cases a coating of shellac varnish, or even a coating of rust, is all that is required, and it should be borne in mind that the space occupied by insulation should always be as small as possible, so as to allow the maximum amount of iron to be used. If the armature is rotated in a simple field between two pole pieces, it is not necessary to subdivide the core to the extent adopted in the earlier Gramme

achines, for since the direction of the eddy currents is at right ngles to the lines of force and to the direction in which the core oves, there will be no tendency for them to flow in a radial irection, but only along lines parallel to the driving shaft. herefore the core may be simply laminated, or built up of a umber of thin discs of soft iron, thus giving better facilities for echanical connection with the shaft, and also reducing the agnetic resistance considerably. In entering or leaving the terior of the wire core, the lines of force have to leap across umerous little spaces of low permeability, while in the case of a re built up of discs, not only is the mass of iron greater, but it also continuous in the direction of the lines, and discontinuous ly in the path which would be taken by the eddy currents.

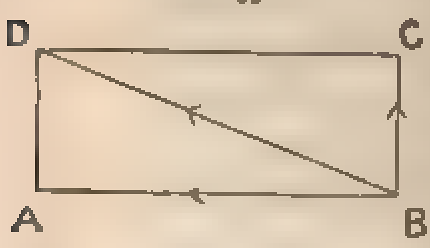
Returning now to a consideration of the phenomena developed y the actual rotation of the armature, we may repeat that the ushes must be so placed that every division between the segents of the commutator passes a brush just at that moment hen the coil, the ends of which are connected to those segments, idle. Now this happens when the plane of the coil is at right gles to the lines of force, so that if the lines of force always ained their regular straight direction between the poles of the ld magnet, it would be easy to fix the correct position for the ushes. But, unfortunately, the field is considerably distorted mediately the armature is caused to rotate and the current ablished. This distortion is [illegible] that the armature lf becomes a powerful ele[illegible]ng lines of force ch are not coincident wit[illegible]agnets.

The two halves of the co[illegible]fact, magnetised the currents passing roun[illegible] manner that similar poles are adjace[illegible] situated at the ts where the two current[illegible]xternal circuit. [illegible] semicircular mag[illegible] e with their [illegible] magnetic [illegible] the iron or ste[illegible] effect ob[illegible] uced with [illegible] ce of th[illegible]

bination. The circle acts, indeed, as if it were a single magnet, the distance between its poles being the length of the diameter. Some of the lines of force find their way back across the diameter to the opposite pole, while others pass round outside the circle, a much larger proportion taking this course when, as in the case of the dynamo, there are large masses of iron in the vicinity. The position of the brushes determines the position of the poles of the armature, and when the brushes are placed on a diameter at right angles to the lines of force of the field, these poles are also at right angles to those lines of force.

It is manifest that as the tendency is for the armature to generate a magnetic field in one direction, while the field magnets strive to maintain one in another, the direction of the resultant field must lie between the two, the exact position depending to a great extent upon the relative magnetising forces of the armature and field magnets. Were these relative forces known, the direction of the field might be determined approximately by the well-known 'parallelogram of forces' (see fig. 155). In this case the line A B represents by its position the direction, and by its length the magnitude of the magnetising force due to the field magnets alone, while the line B C, drawn at right angles to A B, represents the direction and force of the field due to the armature. Then the diagonal B D of the completed parallelogram represents both in magnitude and direction the resulting magnetic field. Now the brushes must be set on a diameter at right angles to these resulting lines of force. Hence this shifting of the field due to the reaction of the armature necessitates also the shifting of the brushes through a corresponding angle, equal, in fact, to the angle D B A.

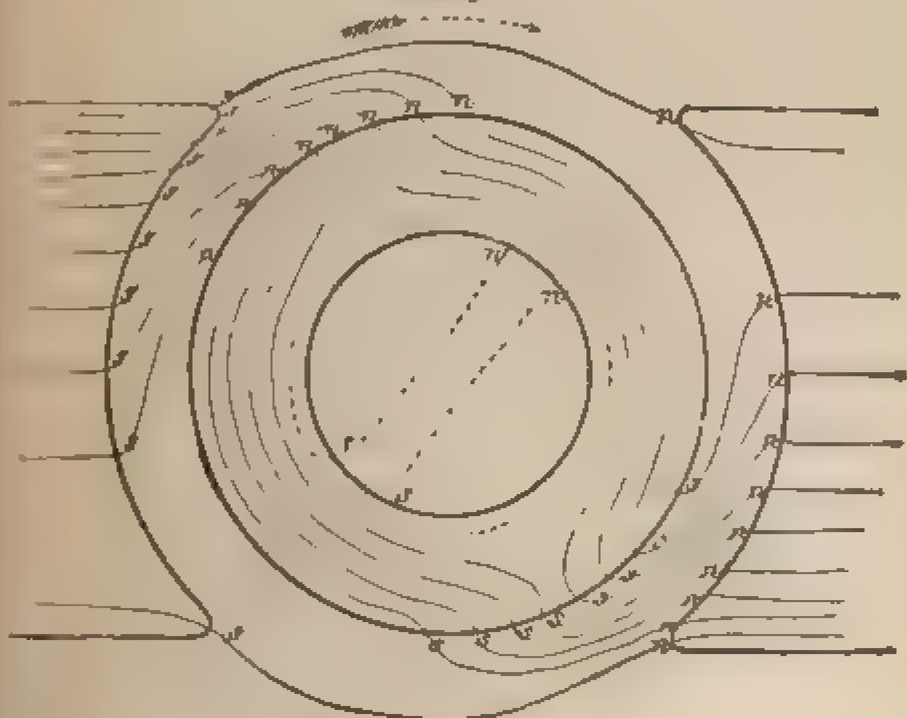
FIG. 155.



This altered position of the brushes is commonly known as the *lead* given to them, and the angle through which they are moved is known as the angle of lead. In every dynamo the lead is forward, or in the direction of the rotation of the armature. But the parallelogram of forces referred to above does not exactly indicate the true angle, because immediately a lead is given to the

bes, the polarity of the armature is shifted through a corre-ding angle, the result being to still further distort the field again increase the angle of lead. It will be evident that e wish to reduce the angle D B A (fig. 155) it can be by decreasing B C or increasing A B, which in either case ld result from making the magnetising force of the field nets great as compared with that of the armature. Practice dictates, for this and for other reasons, that the magnetic in which the armature revolves should be as strong as ible, and always very much stronger than that developed by rmature itself. In fig. 156 is illustrated the direction of the

Fig. 156.



ltant field of a dynamo when the armature is revolving in the ction indicated by the arrow, and is generating a current. It be observed that the lines of force *n s*, *n s* are considerably rted or dragged out of their normal position, and that this rtion takes place in the direction of rotation. The lines h cross the space inside the armature ring indicate the direc-of leakage, corresponding to that illustrated in fig. 148.

When the external resistance through which a dynamo is ing is varied, the current in the armature, and therefore the

field produced by it, also varies; the same cause may also [illegible] the field produced by the field magnets if the machine is 'self-exciting,' and consequently in practice the angle of lead sometimes varies considerably. If the effective fields produced by the field magnets and the armature were varied in the same proportion, the angle of lead would remain constant; but we shall see presently that because the induction through and the permeability of the field-magnet and armature cores do not vary together, as well as for other reasons, this proportion is not maintained, although the currents producing those fields may be equally increased or diminished. Too much stress cannot be laid upon the necessity for setting the brushes in the proper position, and to facilitate matters they are usually mounted on an insulating rocker so that they may be shifted together through a considerable angle until the correct position is found. When the field is a simple one such as that between the two poles of a magnet, and provided it is also uniform, the brushes are placed at opposite extremities of a diameter of the commutator.

When the brushes are not properly adjusted, the coils are short-circuited while they are more or less active, and consequently sparking occurs at the commutator, injuring that important part of the machine, and giving evidence of wasted energy.

Practically the best position of the brushes can be found by shifting them while the machine is running (the external circuit being at the time completed) until there is very little or no sparking observable; and it is found that they must be set even a little further ahead than the point where they are at right angles to the direction of the resultant lines of force. This slight [illegible] necessitated by the rather peculiar and important [illegible] takes place in a coil as it passes a brush. The [illegible] sufficiently wide bearing on the commutator [illegible] interval between the two segments and so to short-[illegible] attached to them for a brief interval [illegible] may take place when the coil is [illegible] itself [illegible] almost inactive, it must be rememb[illegible] self-induction, consisting as it does [illegible] of wire wrapped round a comparati[illegible] We have considered at length th[illegible]

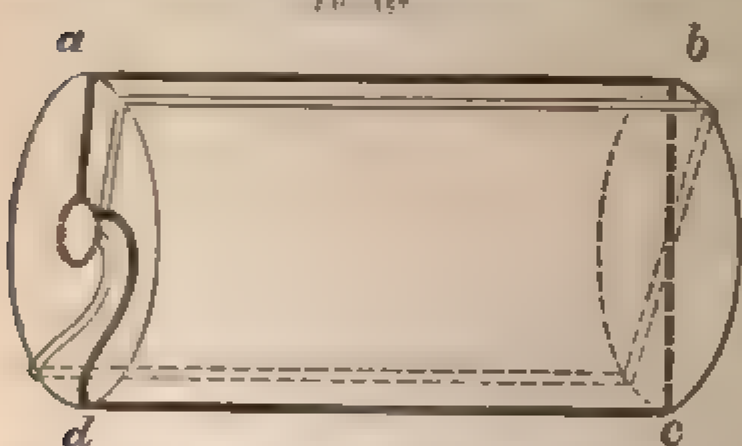
rent being suddenly started or stopped in any circuit which an appreciable amount of self induction, from which it is dent that although the coil itself may not be actually generating y current, yet it is carrying the whole of the current generated the other coils in the same half of the ring, and when short-cuited by the brush this current will not immediately die out, t will become even stronger for a moment and then expire. dependently of this it is impossible in practice to absolutely ain the theoretical condition of each coil being idle even for e briefest possible interval during which the coil might be short-cuited; and although the E.M.F. generated when the coil is t active may be very small, yet its resistance is as a rule so remely low, being but a small fraction of an ohm, that the rent strength becomes perforce considerable. The energy of rents so circulating round the coils while they are in turn short-uited, is expended in heating the wire, which heat represents much energy lost to the external circuit where it might have n usefully employed, and this effect must be remembered one of the many causes which necessitate special attention g paid to *ventilation* in designing a dynamo armature. To re the entire stoppage of the current, and also even to allow cient time for a current in the opposite direction to be just ed in the coil before it is actually thrown into circuit again e other half of the armature, it is advantageous to have the hes rather thick and to give them the slight extra lead above red to

But much can be ... uce the angle of lead and ise sparking by ... strong and construct- the armature ... of few convolutions. ... sts of but one con- ... observed, while, the ... lead is very small. ... of the ... coil ... the ... ced, ... to

tures, commonly known as 'drum' armatures, are constructed upon the principle of the rectangular coil first mentioned. The earliest drum armature was devised by Von Hefner Alteneck, and was really a natural development of the shuttle armature so much used in small magneto machines. This shuttle armature, consisting, as it does, of one coil of many turns, gives a current fluctuating from maximum to zero twice in each revolution, and greater steadiness was aimed at and obtained by placing a number of coils symmetrically round the core, in just the same way that a considerable number of coils wound on the Gramme principle yields a more nearly constant current than would result from a single coil. A drum armature is somewhat more difficult to construct and to illustrate, and although the fundamental principle is in all cases that just indicated, there are many ways of making the necessary connections, some of which will be described when dealing with actual machines.

The general principle may be gathered from fig. 157, where only two adjacent sections are shown, each having one turn. The core is shaped like a cylinder, or drum; a commutator, similar to those already described, being placed at one end in a line with its axis. From one segment the first coil ascends up the face of the drum to *a*, thence lengthways along the cylinder to *b*, whence it passes across a diameter to *c*, and along the length of the cylinder to *d*. From *d* it is brought round the face and connected to the segment next to that one to which the other end of the coil is joined. The second coil, shown by open lines for distinction, starts from the segment at which the first coil terminates, and is wound similarly to that coil, being placed a little further round the drum as shown. Its two ends are connected to adjacent segments, and, in a similar manner, coils would be placed all round

Fig. 157



is only one quarter of that of the whole armature in series, an in calculating E.M.F., the formula, $E = \frac{N\,P\,n}{10^8}$, holds good, P be the number of active conductors, such as $a\,b$, round the periph of the drum.

The drum armature is far more efficient than any other fo and we may briefly compare the relative advantages of the dr and ring type by supposing that we have two armatures of eq diameter, and having conductors arranged round them equa number and length. The magnetic resistance offered by the d armature will be the smaller, because the quantity of iron in core is greater, and therefore a given 'magneto motive force' urge more lines of force through it than through the armature.

Further, the whole of the lines passing through the d armature are usefully cut by the conductors, while, in the cas the ring, some leak across to the shaft and are cut by the in portions of the wire in such a manner as to reduce the main E Therefore, with a given magneto-motive force to maintain field, the drum armature will give a much higher E.M.F. tha ring when they are driven at equal speeds. Equal E.M.F.'s m be obtained by reducing N, the number of lines of force, or P, number of active conductors; but the factor which it is us sought to keep as low as possible is n, the number of revolu per second. One great practical advantage of a drum armat that it enables slow speed machines of comparatively mod proportions to be constructed, and it will be observed that slow-speed dynamos have ring armatures; indeed, the drum pa having recently lapsed, very few simple ring armatures are now in any but small machines. Since the proportion of idle wi slightly less in the drum than in the ring type, its condu resistance is rather lower, while, on the other hand, it has the advantages that it is difficult to make it as strong mechanicall the ring, the cross-connections are somewhat troublesome, and a rule, special arrangements are needed to ensure sufficient ve lation.

Having discussed some of the theoretical points involved the construction and action of direct current dynamo armat

will now consider the methods of maintaining the field, which, ill be remembered, must be as strong as possible. As in the of the more powerful of the machines described in the preng chapter, electro-magnets (called the field magnets) are ployed for this purpose, and great care should be exercised in design. Practical difficulties and economy in construction ewhat influence the shape, but in every case the great object ld be borne in mind, viz. the necessity for leading as many of force as possible through the space between the poles, in h the armature is made to revolve.

The actual magnetising force, consisting of a current passing ugh a coil of wire, is proportional to the amperes of current ing and the number of turns of wire in the coil, and, as has dy been fully explained (Chapter VII.), the quantity repreed by the product of these two factors is referred to as the pere-turns.'

Now, for any given machine, the number of lines of force h must be urged through the armature is usually determined rehand, but as with every electro-magnet, of whatever design, is a certain amount of 'leakage,' only a portion of the lines rated by the ampere-turns pass through the armature.

But power is expended in the generation and maintenance of lines of force, and those which are rendered useless by leakage esent so much power wasted. It is obviously imperative that waste should be reduced to a minimum, and the greatest pos- proportion of the lines developed led through the armature. may be accomplished by making the magnetic resistance of path very low. The whole magnetic circuit should, prefer- approximate to the circular form, and whether good soft iron ast-iron is employed, its sectional area must be sufficient to ent the saturation point being readily reached.

The spaces between the pole pieces of the field-magnet and core of the armature offer considerable magnetic resistance, h may roughly be taken as nearly proportional to the distance een the iron surfaces, the permeability of the copper wire and insulation being about the same as that of air. The only way overcoming this serious difficulty is to reduce the distance een the iron surfaces as much as safety will permit, and, since

this minimum distance is nearly the same in machines of all sizes, we see one reason to account for the observed fact that small dynamos are less efficient than larger ones.

It must not be forgotten that while the permeability of iron decreases with an increase of the magnetic induction through it, that of air remains constant, and the difference between the permeability of the nearly saturated iron of the field magnets, and that of the air space, is never anything like the difference usually given for unsaturated soft iron and air.

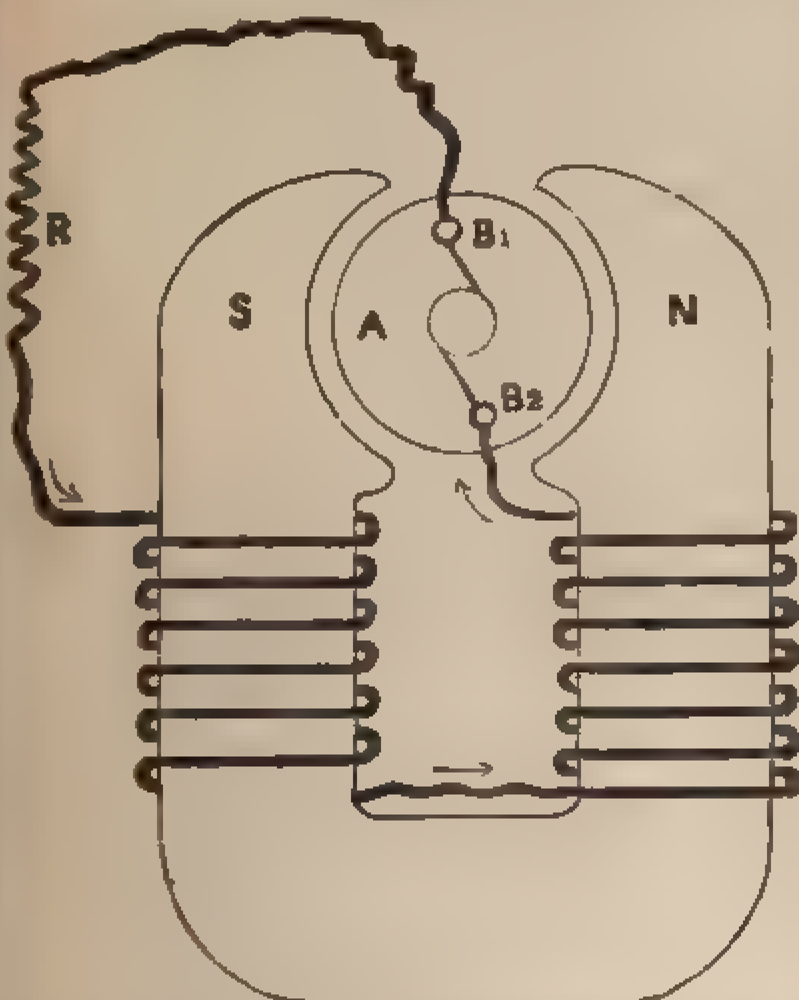
Two very important considerations influencing the construction of field magnets are economy and mechanical strength, and in practice, as we shall see, it is often considered advisable where the weight is unimportant to use cast-iron for part or all of the field magnet core. It is preferable to forge or cast the core in one piece, as joints break the molecular continuity and increase the magnetic resistance considerably; this disadvantage is minimised by making the surfaces in contact fit truly. The principal practical objection to the use of cast iron is that, since its sectional area must be at least twice that of wrought-iron, a much greater amount of copper is required to form the field-magnet coils. Copper, even now, is expensive, while cast iron cores are far less costly than equivalent ones of wrought iron, and the student should observe how different makers aim at true economy in this matter. Even leaving out the question of cost and weight, it does not by any means follow (as is sometimes supposed) that a dynamo properly designed to perform certain work, and having cast-iron in its construction, is inferior to one built wholly of wrought iron to perform the same work.

The composition of the 'ampere-turns'—that is, the proportion of current strength to the number of convolutions—will depend largely upon the manner in which the exciting current is obtained; for it is sometimes necessary to have considerable resistance in the coils, and then the number of convolutions may be made great and the current correspondingly weak; while in other cases a high resistance is inadmissible, when only a few turns can be employed, and the necessary magneto-motive force must then be obtained by the aid of a heavy current.

At the beginning of this chapter we referred to a very impor-

benefit following the commutation of the current, viz. the
ility of using all or part of the current generated in the
ure for the purpose of magnetising the field-magnets, and
mplest method of doing this, in which the whole of the
nt is so employed, is exemplified in fig. 158. A machine

Fig. 158.



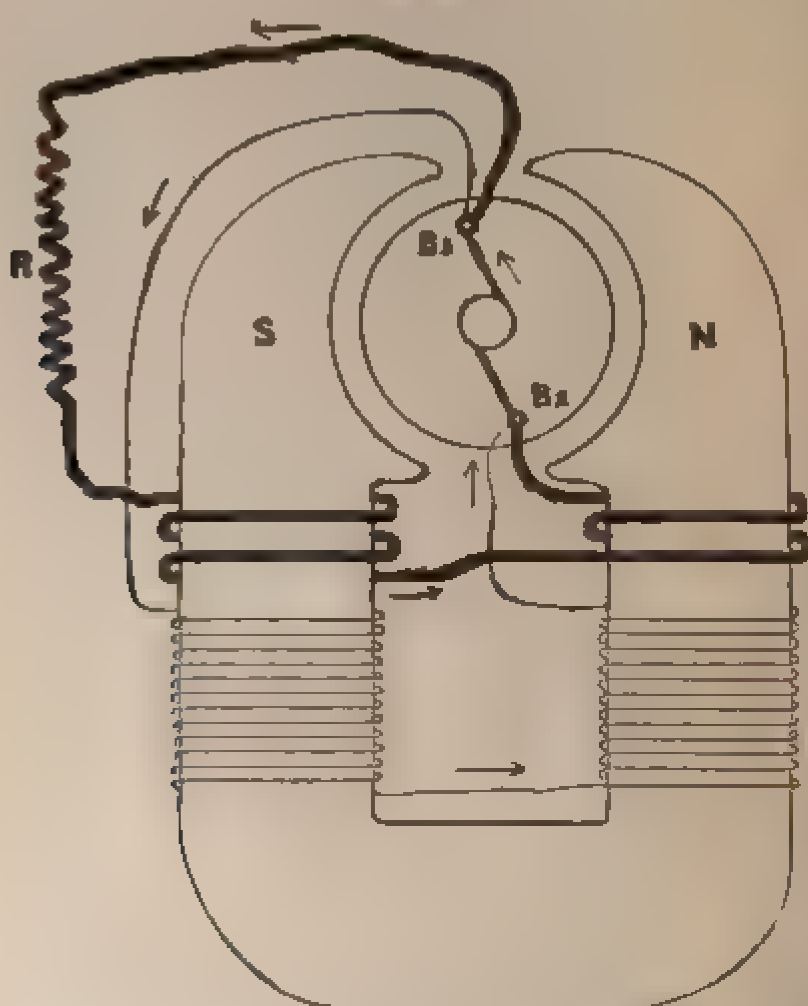
g its connections made in the manner there shown is known
Series Dynamo.'

s are the pole-pieces of a massive horse-shoe electro-
t; the armature A revolves in the space between them, B_1 B_2
the brushes which press against the commutator, and by
of which the current generated in the armature can be led
desired point. In this case, one end of the wire forming
il of the electro magnet is connected directly to the brush
e other end being joined through the external circuit R to

manner just described is only self-regulating at a given speed for at any other speed the two windings do not compensate each other.

In the case of a series machine, if, for instance, the speed were doubled and the external resistance increased sufficiently to keep the current the same, the strength of field would remain unaltered and the E.M.F. would be increased almost, but not quite, two-fold

FIG. 167.



by the doubled speed. On the other hand, if, with a shunt dynamo, by increasing the external resistance we maintain the external current constant when the speed is doubled, the current in the shunt coil, and therefore the strength of the field, increases instead of remaining the same as does that of a series dynamo. ...le, if at the doubled speed the resistance were reduced to make ...rent in the shunt coil the same as at the lower speed the ... current would be greatly increased in strength. Therefore

number of watts of power developed therein, or W = E C, W g the number of watts.

As the E.M.F. is equal to the product of current strength and tance (that is, E = C R), we may write $W = CR \times C = C^2 R$ – is, the power in watts developed is equal to the resistance in s multiplied by the square of the current strength in amperes.

As the resistance of the dynamo armature and magnet coils is ys known, only one measurement, that of current strength, d be taken, which can be done by any ammeter of negligibly resistance.

Supposing, for example, the resistance of the armature to be hms, and that of the field-magnets to be 2 ohms, then the total tance is 5 ohms. When a current of 10 amperes is generated out any external resistance, the electrical power appearing he circuit is equal to $C^2R = 100 \times 5 = 500$ watts, and if the ent is increased to 20 amperes, then $C^2R = 400 \times 5 = 2{,}000$ s.

Now, in both cases at least as much mechanical power is re- ed to turn the armature as appears in the circuit as electrical er. A certain amount in excess is necessary (depending upon efficiency of the machine), because some energy must be ed in overcoming the mechanical friction of the bearings, &c., still more by various electrical causes, such as eddy currents the currents which flow in the coils during the period of t-circuiting.

The main point, however, upon which we desire at present to stress is that the increase in the current is not, and never can obtained without a corresponding increase in the power ex- ded in turning the armature; in fact, from the above reasoning clear that in a series dynamo such as the one described, the hanical power expended varies as the *square* of the strength of current obtained in the external circuit, ignoring the mechani- power lost in the machine during conversion.

The ultimate strength of the current is, then, limited not only he saturation of the field-magnets, but also by the amount of er at our disposal to drive the armature round. The engine, her source from which the power is derived, must at least be to furnish power equal to the maximum electrical power it is

desired to obtain, to which must also be added that which is wasted in friction, &c.

With regard to the residual magnetism which is relied upon to start the current, it may be remarked that if the field-magnets are once strongly magnetised by a current passing in the direction in which it is desired the currents shall afterwards be generated, the cores will rarely lose all traces of magnetism, especially if of cast iron. This sometimes happens, however, when the dynamo is moved, and the magnetism may even be reversed; but matters can easily be righted by passing a current, say, from a few cells for a moment in the proper direction through the field-magnet coils.

Hitherto, the dynamo has been considered as only working on 'short circuit' that is, with the circuit completed without the introduction of any appreciable external resistance. In practice we require the current to do a greater or less amount of work in an external circuit, such as developing light in electric lamps or driving an electro-motor. In such a case, part only of the power is expended in overcoming the internal resistance (that is, the resistance of the armature and field-magnets) and maintaining the field, the remainder being employed in the external circuit. It is easy to find the relative amount of power absorbed in the two parts of the circuit. Thus, suppose the strength of the current to be 40 amperes, and the total E.M.F. to be 80 volts, then the total electrical power is $40 \times 80 = 3{,}200$ watts. If, now, the difference of potential between the two extremities of the external circuit is found to be 60 volts, the power absorbed therein is $40 \times 60 = 2{,}400$ watts, for the strength of the current is the same in all parts of the same circuit. The remaining difference of potential is $80 - 60 = 20$ volts, which is the fall along the internal circuit, and which absorbs, therefore, $40 \times 20 = 800$ watts. In this way the ratio between the power spent in the external and internal portions of the circuit can in every case be measured. The two ends of the external circuit above referred to are called the 'dynamo terminals,' and the potential difference thereat can be measured by any convenient voltmeter. Since, also, the power spent in either portion can be calculated by multiplying the square of the current strength by the resistance of the respective portions of the circuit, and as the current is the same in each, it follows that the ener

number of watts of power developed therein, or W = EC, W
the number of watts.
s the E.M.F. is equal to the product of current strength and
nce (that is, E = CR), we may write $W = CR \times C = C^2R$—
, the power in watts developed is equal to the resistance in
multiplied by the square of the current strength in amperes.
the resistance of the dynamo armature and magnet coils is
known, only one measurement, that of current strength,
be taken, which can be done by any ammeter of negligibly
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is increased to 20 amperes, then $C^2R = 400 \times 5 = 2{,}000$

in both cases at least as much mechanical power is re-
turn the armature as appears in the circuit as electrical
A certain amount in excess is necessary (depending upon
ency of the machine), because some energy must be
overcoming the mechanical friction of the bearings, &c.,
more by various electrical causes, such as eddy currents
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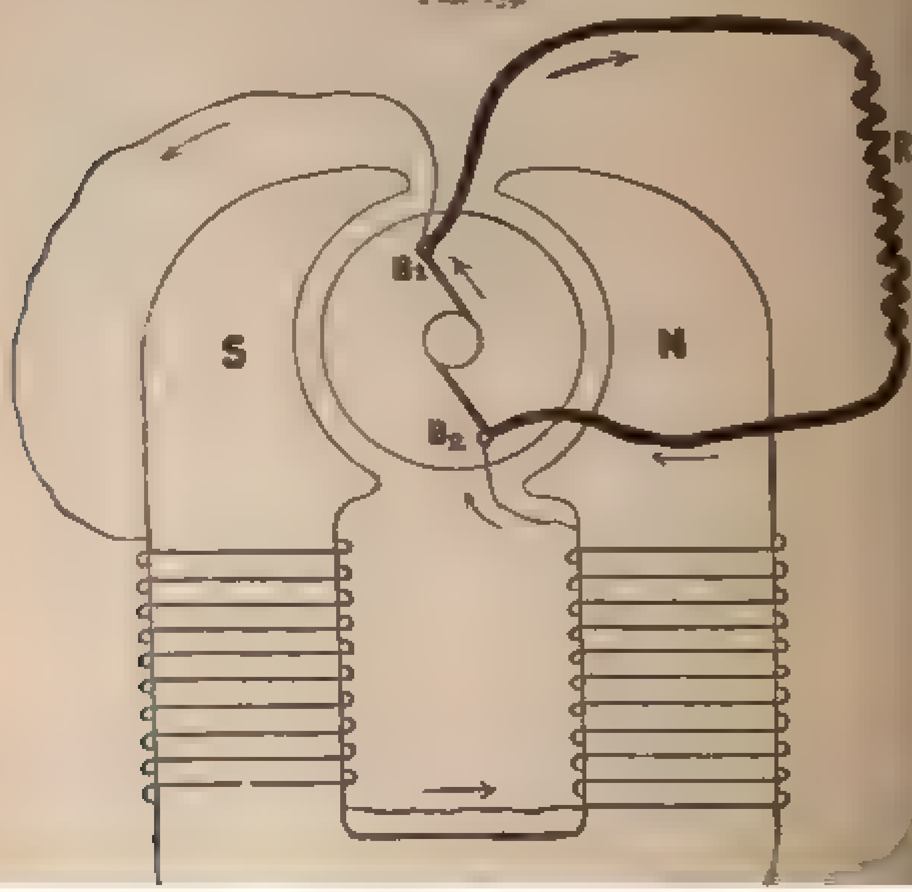
dynamo such as the one described, the
ries as the *square* of the strength of
nal circuit, ignoring the mechani-
ng conversion.
urrent is, the ed not only
, but als amount of
he engine,
least be
wer it is

In the shunt dynamo the field-magnet coils, instead of joined up in series with the armature and external circuit, connected that they form a 'shunt' *to the external* receive, therefore, only a part of the current generated armature, the proportion depending upon the relative resi Fig. 159 shows the manner in which the connections are

Fig. 159.



f the latter. But wrought iron is employed for the actual round which the field magnet coils are wound, each core, onsisting of a slab of special soft hammered scrap-iron; ving the advantage, previously referred to, of economising wire, by obtaining the requisite magnetic conductivity e minimum sectional area. The pole-pieces are of grey n, and the sectional area of all the cast-iron portions is

Fig. 170.

atly increased to compensate for the lower permeability as ed with that of the excellent iron forming the core. It is, er, evident that as the lines of force begin to pass into the re from the bottom of the pole-pieces, fewer lines pass the upper part of it than through the lower, and conse- there is no advantage in having the iron of the same ss throughout. The pole pieces, P P, are in this case so

tained by multiplying togeth
through the armature by its
power developed is 21,024
absorbed in maintaining the f
resistance, the remaining 20,
external circuit.

The ratio of the power u
developed is commonly known

dynamo, and in the case just

the electrical efficiency is sligh
necessary to point out that a
ture resistance would considera

Ignoring for the moment th
ism, it will be observed that in
become demagnetised immedia
because the whole of the curre
a shunt dynamo, however, if th
broken, there is an alternative
by the armature, viz. round the
of the current will then pass th
of only a portion of it, the str
magnet is always at its maxim
connected; exactly opposite to

nges in the external circuit than the series dynamo, neither n is, for many purposes, sufficiently 'self regulating,' or able mmodate itself to these external variations. We may require mo to do one of two things: either (*a*) to regulate itself o send a *constant current* or a current of uniform strength h the external circuit, although the resistance may be con-bly varied; or (*b*) we may require it to maintain a *constant tial* at the extremities of the external circuit—that is, at the es—under like variations of resistance. A machine cannot nstructed to fulfil both these requirements, and we will first ler the best of the many methods of maintaining a constant tial. This consists in the combination, in one machine, of ries and the shunt methods of winding. The simplest way, ps, of viewing the arrangement, is to consider the machine hunt-wound one, having added to it, round the magnet-a few turns of wire in series with the external circuit. when the external resistance is made very low, and, as a quence, the current in the shunt coils reduced to almost g, the magnetic effect of the series coils becomes a maxi-so that the opposite variations in these two sets of coils o keep the field more or less constant. It is clear that the s attending this combination will depend largely upon the proportions being given to the shunt and series coils, and er to ascertain what these proportions are or should be for articular case, we will now introduce a convenient method ich the variation of the E.M.F. developed by a dynamo under g conditions can be studied.

t us start with the case of a series machine, driven through-e experiments at a constant speed, and joined up to a set of le known resistances which can be varied as desired. The ng current can be measured by any suitable ammeter, he resistance of the machine and of the external circuit known, the whole of the E.M.F developed can be calculated product of amperes and ohms. We thus obtain the es of current flowing and the whole of the volts of E.M.F. ped, and these two quantities may be similarly found for mber of values which we choose to give the external nce.

The speed of the machine is 1,050 revolutions per minute, at which it is capable of giving a current of 75 amperes, with an E.M.F. at its terminals of 100 volts.

The brushes consist of flat tough copper strips, fixed in adjustable holders, which are carried by the horizontal arms projecting from the rocking lever, as shown in fig. 169. This lever is provided with an insulating handle, by means of which it can be rotated in either direction round the axis of the shaft, thus affording facilities for altering the lead of the brushes to suit the requirements. It is carried on a projection from the standard supporting the bearing, and is made in two pieces bolted together, so that it can be readily tightened up on its bearing, or, if necessary, removed. The horizontal arms are insulated from the lever by hard fibre collars; and spiral springs, with adjusting screws, are provided for varying the pressure of the brushes on the commutator, the pressure being always as light as is consistent with reliable contact.

The brushes are shown lifted from the commutator; and it will be observed that they can be adjusted along the bars, so as to press upon different parts when the machine is running, and thereby distribute the wear. The commutator is turned up perfectly true in a lathe with a fine tool which cuts the copper cleanly and does not drag or burr it over the mica strips.

The shaft-bearings are of phosphor bronze, and the rim of the pulley is perforated to afford a better grip for the belt.

Most machines are, however, now made of the drum type, and fig. 172 illustrates a drum-armature dynamo constructed by the same makers. The general proportions of the field magnets are somewhat similar to those of the machine already described, but the method of fixing the parts together differs. The two vertical bolts passing through each of the pole-pieces extend only about halfway into the wrought-iron cores. Each core is lengthened a little, and, fitting into a slot in the cast iron bed-plate, is held firmly in position by two horizontal bolts passing through the solid parts of the casting. The core is built up in a manner somewhat similar to that adopted for the ring machine, but the radial depth of the discs is somewhat greater, and the driving-spider is made of iron instead of gun-metal. The armature conductor is composed of

...ection of *corresponding* ordinates and abscissae being ... the curve. The length of the side of a square in the ... presents 10 volts or 10 amperes, but in practice it is better ... larger sheet of paper divided into a greater number of ... one side of each square representing 1 volt or 1 ampere ... e may be. One of the experiments with this machine ... that 70·6 volts were developed when 18·2 amperes were ... and the point A on the curve is the result of this particular ... nt. It is the point of intersection of the two straight ... and D A, drawn at right angles to O Y and O X respec... A being 18·2 units and D A 70·6 units in length (the unit ... e-tenth of the side of one of the squares). Another ex... which determined the position of the point B, showed that ... es were flowing when 87·4 volts were developed; therefore ... ence E B is made equal to 42 units, and F B to 87·4 units. ... oints were fixed by similar experiments, and by joining ... nts together the curve was obtained. Considerable care ... exercised in performing the necessary experiments to ... e one of these curves, and in the region of any decided ... n the curvature the number of experiments must be ... han in the more uniform portions of the line. Notwith... however, the exercise of the greatest possible care, some ... oints are usually placed a little out of position, owing to ... ntal error. But experience and theory teach us that ... viations never appear in the curves of dynamo machines ... hen the points do not lie exactly on a regular curve, we ... certain extent, correct experimental errors, by striking ... be called an average, with the aid of a flexible ruler.

... the amperes and volts to increase in the same proportion ... , the 'curve' would be a straight line; but with every ... g series dynamo we get a curve somewhat similar to the ... ven—that is to say, with ... part ascending rapidly, ... d bend, followed by ... ght portion making ... with the horizon ... ready been pointed ... the ... rise ... flowing round the ... ... as th... ... eld) increases, ... nt does not ... in th... ... pens when the

iron in the field magnets becomes saturated, and it is at this stage that the decided bend in the characteristic curve shows that the amperes are increasing faster than the volts.

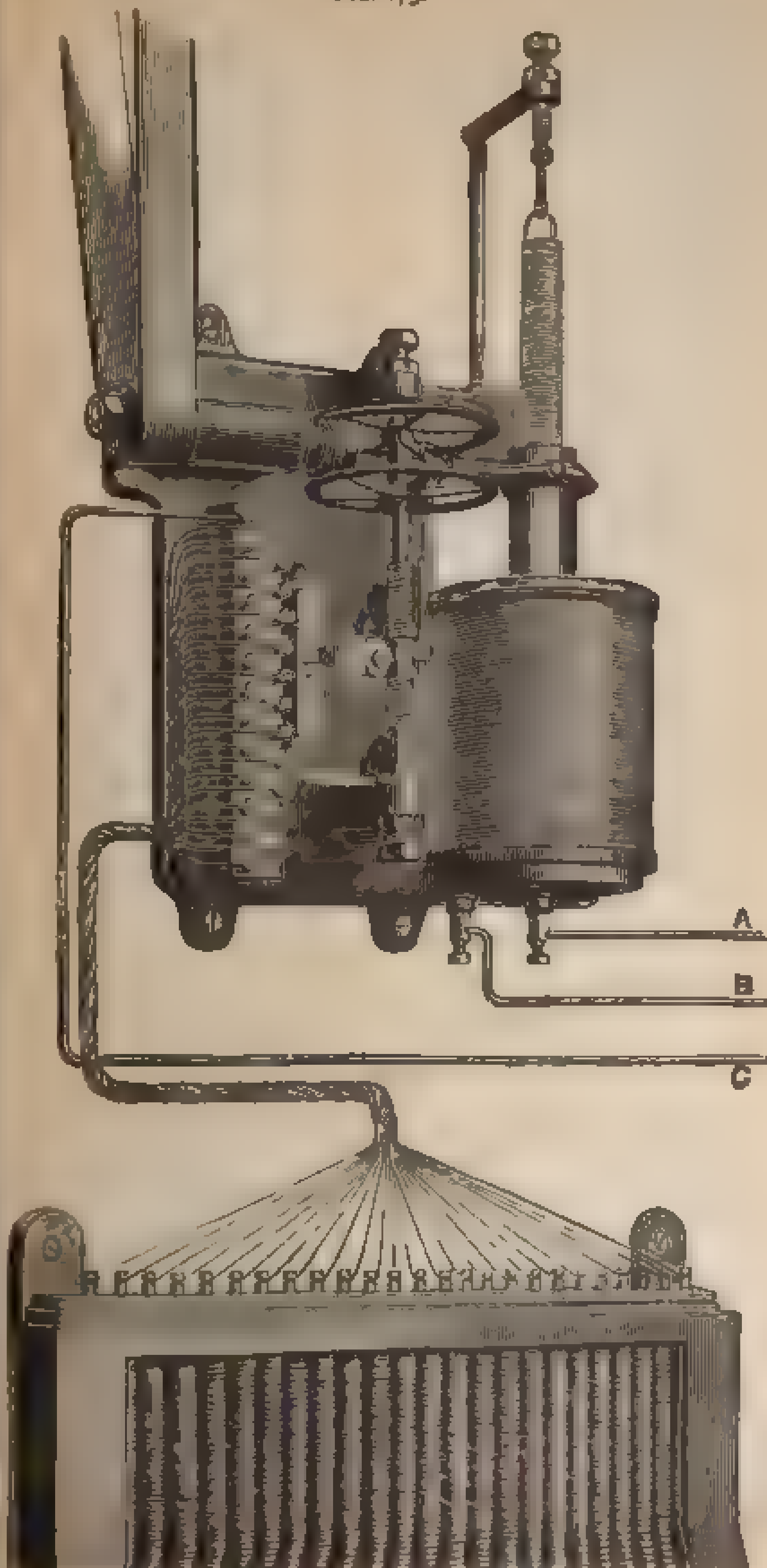
It sometimes happens that by merely glancing at a curve we can criticise the design of a machine in some important respects; for instance, the effect of having too little iron in a machine would be to make the bend occur earlier than it really should do. Other points of criticism will manifest themselves presently.

Reverting to fig. 161, it will be seen that the curve commences, not exactly at the point O, but at a point a little way up the vertical line, thus apparently indicating the existence of a small E.M.F. before the current commences to flow. This actually is the case, and results from the existence, in the field-magnets, of residual magnetism, which provides a weak field and produces a small E.M.F. at the terminals before the circuit is completed.

The two quantities—current and E.M.F.—plotted in this curve, are those which, when multiplied together, enable us to estimate the amount of power being developed in the whole circuit, for the product of one volt and one ampere is one watt, which is the electrical unit of power, or rate of expenditure of energy, and 746 watts correspond to one horse-power. It follows that we can select any point on the curve and readily calculate what power was being developed in the circuit at the particular moment that the point was determined; for instance, during the experiment which determined the position of the point A, the power developed was $70{\cdot}6 \times 18{\cdot}2 = 1{,}284{\cdot}92$ watts.

Such calculations can, in a measure, be avoided by the addition of another set of curves cutting the characteristic at points which correspond to a certain horse-power or fraction of a horse-power. Fig. 162 is a copy of fig. 161, with a number of these horse-power curves added in dotted lines. At the point M, where the characteristic cuts the 1 horse-power line, the product of volts and amperes is equal to 746 watts, while at K it is equal to $2 \times 746 = 1{,}492$ watts. Now, if the dynamo is driven at a higher speed, the E.M.F. for a given current will be greater—that is, the vertical distances will be relatively greater than the horizontal ones as the speed is increased, and a curve somewhat similar in shape but [illegible] above the existing one, will be obtained. Several curves

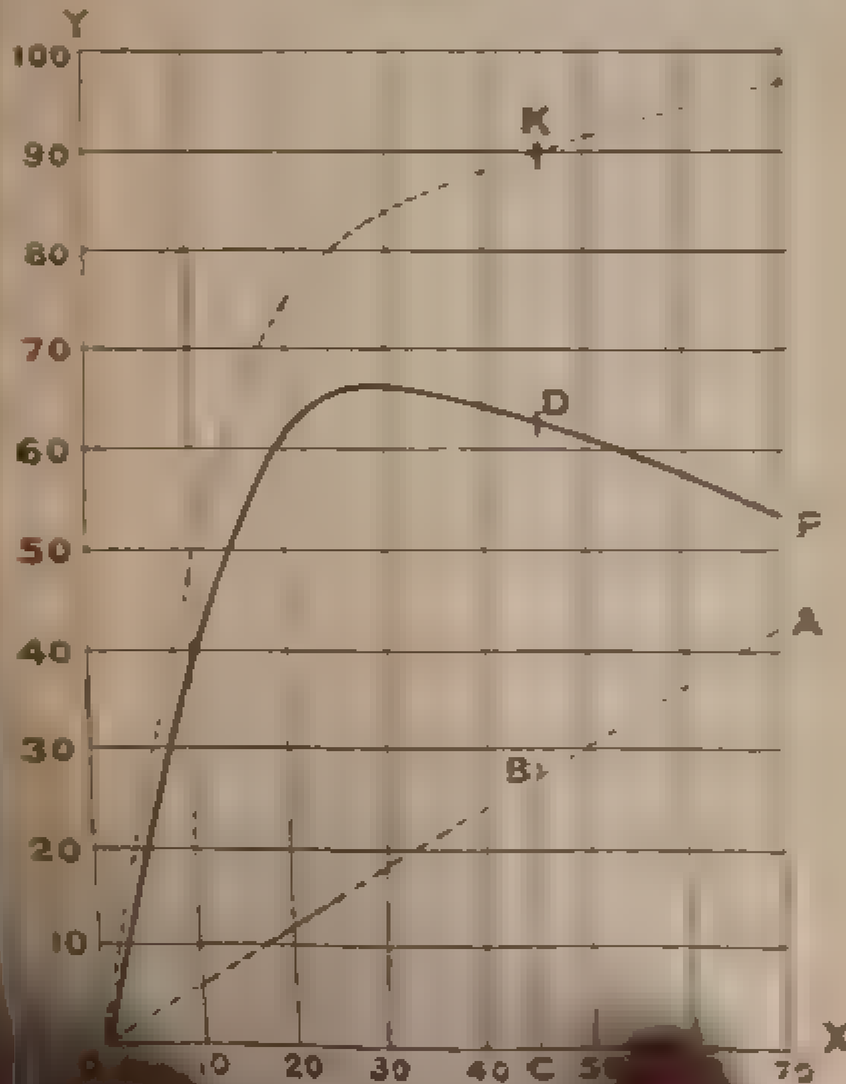
FIG. 173.



such that the motion imparted to the spindle, due to an increa
of E.M.F., moves the flat spring in the direction which throws mo
resistance in series with the field-magnet coils, while if the core
moved upwards, the lower wheel engages with the friction di
and rotates the spindle in the reverse direction, reducing th
resistance in the field-magnet circuit.

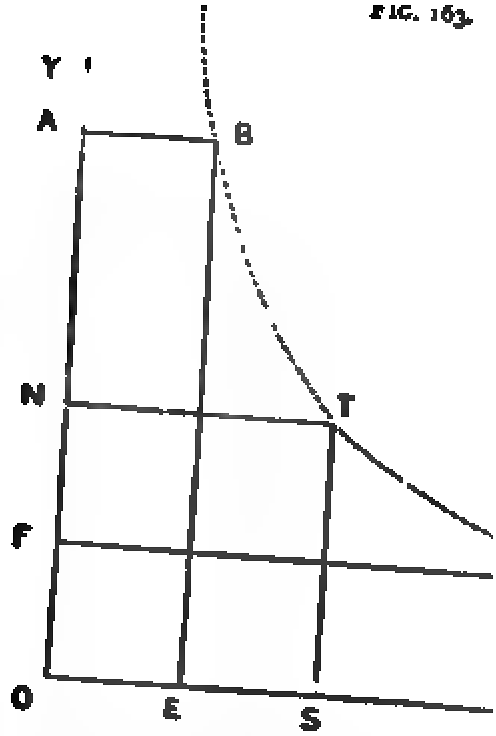
The solenoid is subject to the same heating error as a vol
meter, and to minimise this it is more frequently wound wi
fairly thick wire, the temperature of which rises but little, and th
necessary resistance is obtained by joining in series with it Ge
man silver coils, which have a lower temperature coefficient, and
being left bare, dissipate heat readily. When the apparatus is re
quired to maintain a constant current, the solenoid is wound wi
thick wire, and is joined up directly in the main circuit, the ri
and fall of the main current which passes through it acting in th
same way as a rise and fall of potential at its ends. The smal
horizontal shaft is driven at about 400 revolutions per minute, an
the nut carrying the contact spring can then travel over th
whole range in about ten or twelve seconds. The flat spring is so
broad that the circuit is never broken during the movement of th
spring, and a large number of coils is employed in order that th
increase or decrease of the resistance shall take place gradually.
The weak point about the apparatus, as depicted in fig. 173, is th
means adopted for imparting circular motion to the light wheels
for, although the friction between the rubber disc and the whee
rim is at first quite sufficient, it becomes uncertain and unreliabl
if the rubber gets dirty or covered with oil. To overcome thi
difficulty an entirely different gearing has been adopted in th
later apparatus, the essential parts of which are shown in fig. 17
R is the contact spring, carried by the nut N, working upon th
screw shaft G, up and down which the nut travels according to th
direction in which the screw is turned. The screw forms th
lower part of the vertical spindle F G, upon the upper part o
which is fixed a pin-wheel A, that is, a flat disc having a numbe
of pins fixed parallel to its axis at equal distances round its ci
cumference. Behind the spindle and parallel to the plane of th
disc are two endless screws D, E, the upper one being at the end o
the shaft, which is driven by a belt on the pulley P. By means

teristic curve, is the [illegible]
the external potential difference [illegible]
Fig. 164 the curve [illegible] the external [illegible]
the same [illegible] the [illegible]



[illegible] end is now even more [illegible]
[illegible] potential differ[illegible]
[illegible]
[illegible] of the [illegible]
[illegible] in the arma[illegible]
[illegible]
[illegible] live [illegible]
[illegible]

FIG. 163.

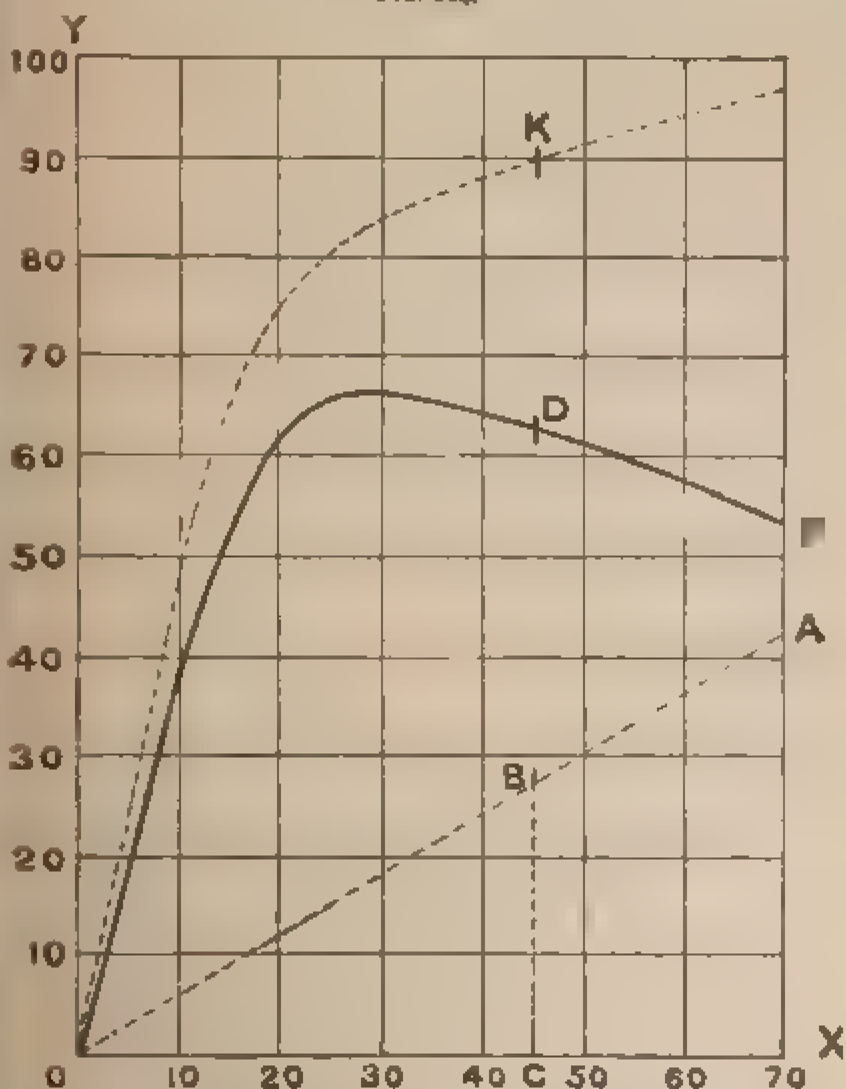


O E being half that length). T
are each equal to 746, B an
method illustrates the princip
methods of finding pairs of
suggest themselves (Euclid, I
determining the first point o
$\sqrt{(2 \times 746)} = \sqrt{1492}$, conseque
in the ...

cteristic curve, is the more useful of the two, for in practice he external potential difference which concerns us most.

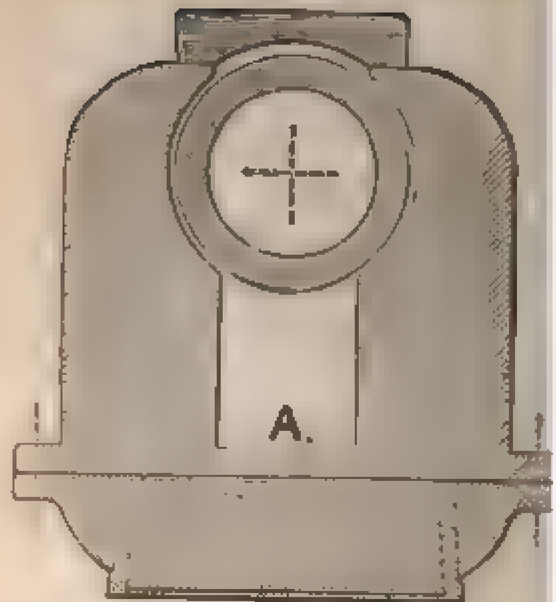
fig 164 the curve O P is the *external* characteristic, obtained the same machine as the previous curve, running at the

FIG. 164.



speed. The bend is now even more clearly defined; in fact, a certain point, the potential difference falls as the current eased. One reason for this bending down is, as we have the magnetic saturation of the iron, and it is also partly l by the heavy current in the armature distorting the field. urve shows us then, at a glance, the particular current h at which we can get the maximum external potential nce at a given speed, and, of course, by inserting the horse-

Fig. 177.



viously described, but the armatu
brackets bolted to the bed plat
pulley is grooved for rope gearing

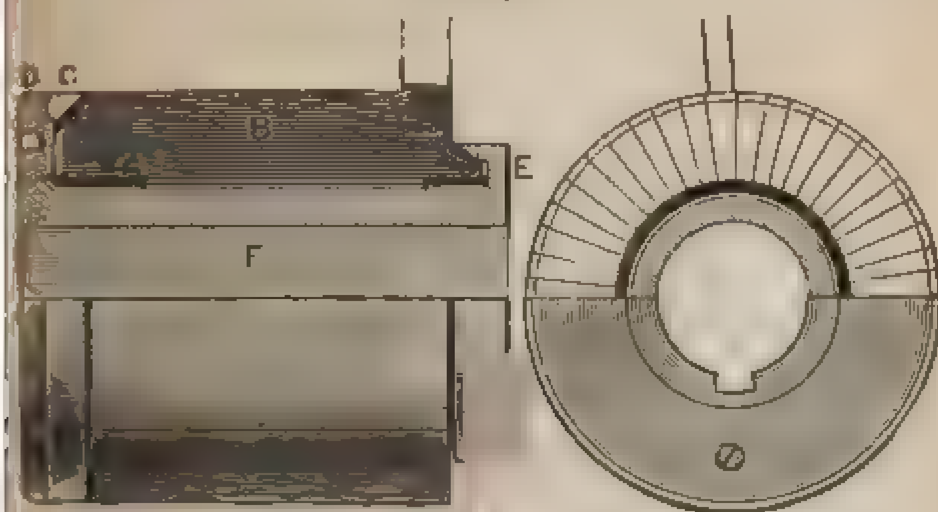
The brushes are made of soft
iron machine each brush is co
adjustable sections, the holder ro
gun-metal bracket.

The commutator consists of
drawn copper or gun-metal casting
gives two views of th

by means of mica, and from the bush E and ring C by sheets ite fibre, indicated by the thick lines in the figure.

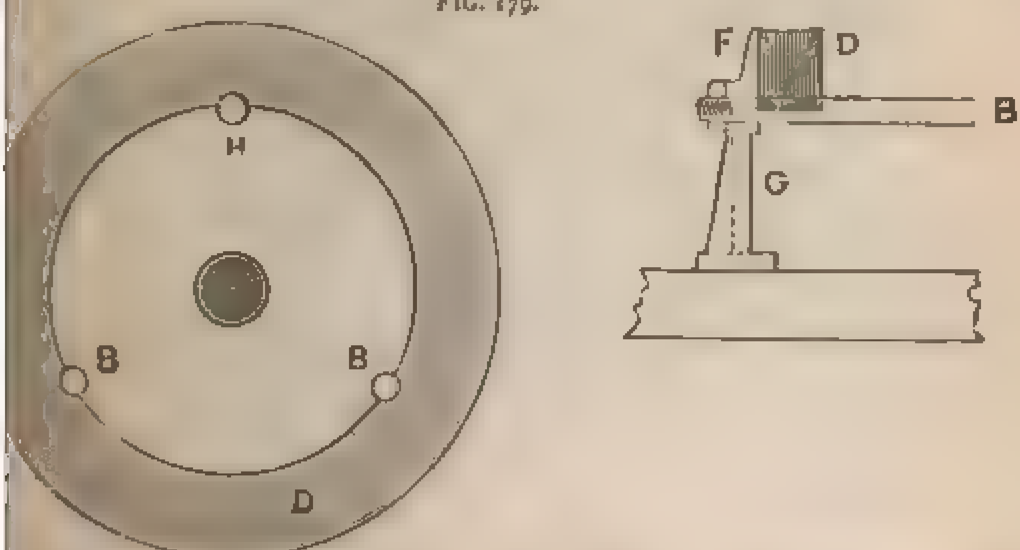
he armature is of the ring type, and its core is built up of a er of thin soft iron rings (D, fig. 179), insulated by paraffined

FIG. 178.



r, and the whole firmly clamped together between two end es by three delta metal bolts, B, semicircular pieces being ped out of the iron rings to fit these bolts. A gun-metal

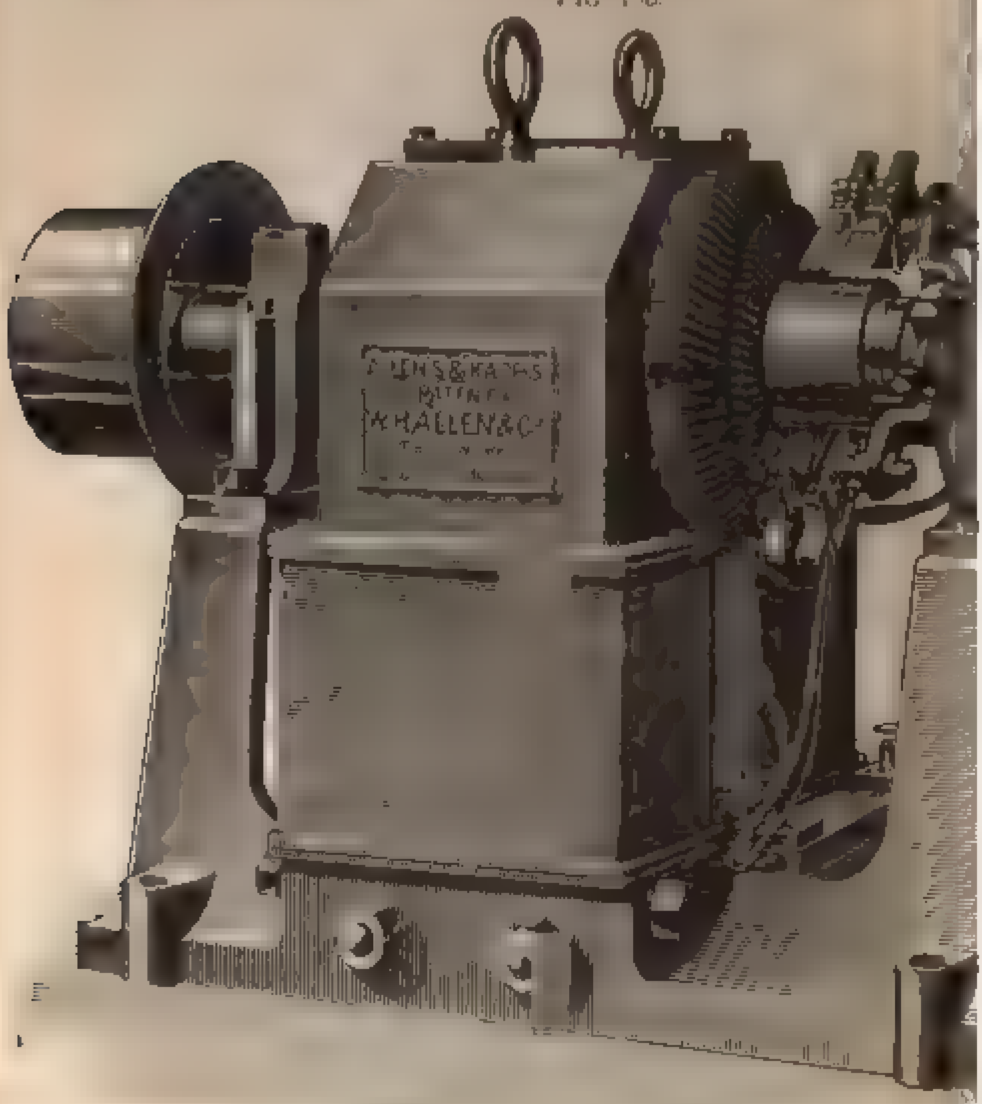
FIG. 179.



r with three radial arms, G, is keyed on to the shaft at each of the core, the bolts passing through their extremities as at F. One size of the machine illustrated in fig. 176 has an output 500 watts at 100 volts (65 amperes) when driven at 1,300

revolutions per minute. It is compound wound. Th
of the armature is 0·03 ohm, and of the shunt coil
the series turns being wound inside the shunt coil a
resistance of 0·018 ohm. From these figures the
calculate the power spent in the various portions o
when the maximum current of 65 amperes is flowing.

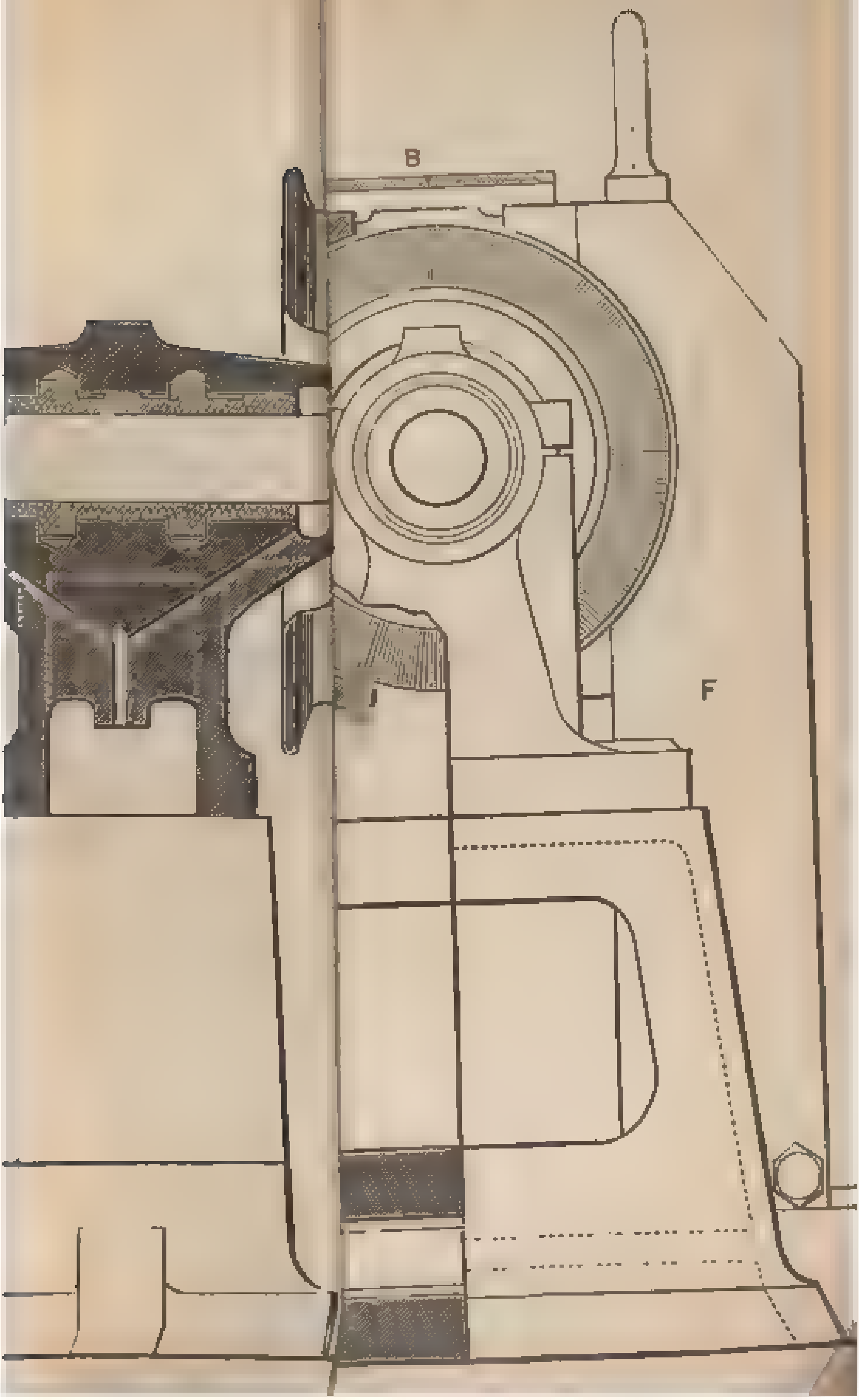
FIG. 180.



A general view of the dynamo designed by Mr. G
and constructed by Messrs. W. H. Allen & Co. is given
The field magnets are also of the inverted horse-sh
which, it should be mentioned, Mr. Kapp was the first

To face page 332.

FIG. 182.



object being to minimise, as far as possible, the magnetic leakage, as will be further explained presently. The armature in the machine illustrated is of the ring or cylinder type, but very few Kapp machines are now made with this class of armature. The drum and ring types are, however, very similar in external appearance, the chief difference being that due to the greater projection of the drum armature on account of the space taken up by the cross-connections.

Figs. 181 and 182 illustrate many details of a recently-constructed drum machine, the former being a longitudinal section, and the latter an end view, half in section.

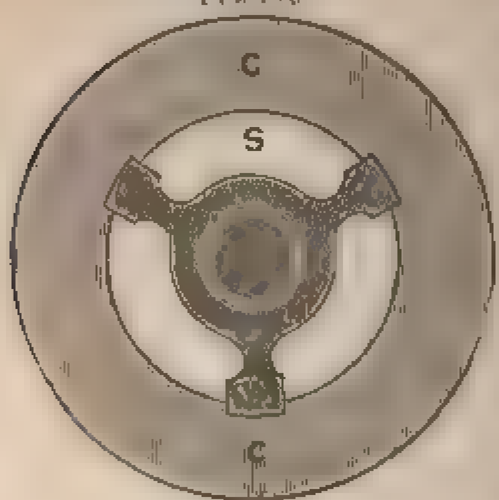
Each field-magnet limb, F, consists of a single slab of wrought-iron, the lower end of which fits into a slot in the cast iron bed-plate. The bed-plate is solid at this part, and the vertical limbs are secured in position by two large bolts passing through, as shown in fig. 182. The pole-pieces are bored out circularly to form the space in which the armature is to revolve, and the horns are securely pinned on. Upon the upper horns is fixed a board B, which acts as a cover to protect the armature. The field-magnet coils are of cotton-covered copper wire and are wound on frames or bobbins of thin sheet steel, *b b*, insulated with varnished paper, the bobbins being slipped over the cores after the wire has been wound.

The construction of the armature, which is well-designed and built with extreme care, is shown in fig. 181. H is a cast iron hub, having three radial arms, W; it is securely keyed on to the steel shaft, its length along the shaft being equal to the length of the finished core. The extremities of the arms are planed to fit into notches in the core plates, C, as shown in *fig. 183*, which is
section through the armature core and hub taken at right
to the shaft. The core plates are of thin charcoal ir
tween them at equal intervals are placed three p
rigid plates, which are kept a little distance apart b
fibre, thus affording spaces for the circulation of
rposes. The plates are separately well varnish
; and while under high pressure between term
e core is slotted to receive the arms, W, of the
g of figs. 181 and 183 corresponds. In the f

is shown directly below the shaft, while above it is the air-space s, between the other two arms.

At one end of the shaft is provided a solid boss, K, and against this bears a cast-iron plate, P, in which are inlets, D D, for the passage of air. The core is held between P and a similar end plate, R, which is secured by a steel nut, N, screwed on to the shaft.

FIG. 183.



The ventilation is thus most efficient, for the air can enter through each end-plate by openings similar to D, and find its way along the spaces, S, between the hub and the plates, leaving by the openings between the rigid plates previously referred to.

Before being wound the core is turned in a lathe to obtain a perfectly cylindrical and smooth surface. At intervals round the thicker plates there are projections, which serve to drive the conductor and prevent its being stripped. These projections are shown on the middle pair of plates in fig. 181, and, in addition to these horns, the completed armature is bound round in several places with thin strong wire which effectually overcomes any tendency towards bulging or stripping.

There are 204 active conductors round the periphery of the armature, each consisting of a straight strip or bar of copper, 0·0215 sq. in. in sectional area, insulated with a double cotton covering. They project to different distances over the edge of the core, and are soldered to the ends of peculiarly shaped copper strips which form the cross connections.

One of these connecting strips is shown in fig. 184. It is a stamping of sheet copper and forms almost, but not quite, a semicircle, because it is required to extend round the end of the armature just far enough to connect two bars which are almost at opposite extremities of a diameter. The connector is placed with its plane parallel to the plane of the core discs, and the two small end pieces or tags, *c c*, are bent round at the part shown by the dotted lines until they are at right angles to the other portion of the

ends of the two conductors which are to be joined toge-
lered to these pieces (*e e*). In fig. 181 the conductor
ed to the tag *e*. Each section of the armature consists
olutions, that is, four active conductors, and the cross-
occupy a comparatively small space, a section through
f them being shown at L L. Over the shoulder of each
fixed a cast iron ring, T, with a wide deep groove in
onnectors are placed, each well
y being over-wound with tape
a shellac varnish. There are
s in the commutator, and the
olding them in position is shown
udinal section. They have two
hes, into which fit rings of hard
bre, the sections through which
lack in the figure, and it will be
at there is a deep groove on the
f each ring. A gun-metal sleeve
to the shaft, one end fitting
ove of one insulating ring, while
cut round the other end for a
when screwed up home, presses
l ring into the groove of the
ing. The commutator bars are
om each other by mica, and
is divided into two indepen-
table parts, this being a better
t than one wide brush, which would probably wear
d, in consequence, cause a considerable variation in the
surface contact. The sectional view also shows the
hich the rocking bar is carried round a groove at the
cast-iron standard, and the fixing of the horizontal
les, which are insulated from the rocking bar by hard
s. Various other mechanical details are set forth in the
t perhaps it should be mentioned that the radial lines
ter edge of the armature in fig. 182 indicate the edges
l pieces, *e e*, of the connectors.

chine is shunt-wound, and, when driven at 680

FIG. 184.

lines.

The unit of magnetic inducti
by Mr. Kapp, who considered it
poses than that based on the
equal to 6,000 C.G.S. lines, and
square inch instead of the squa
perhaps, in some respects, u
probably survive, as it is alread
manufacturers. The conversion
of course, be accomplished wi
that one square inch contains ab

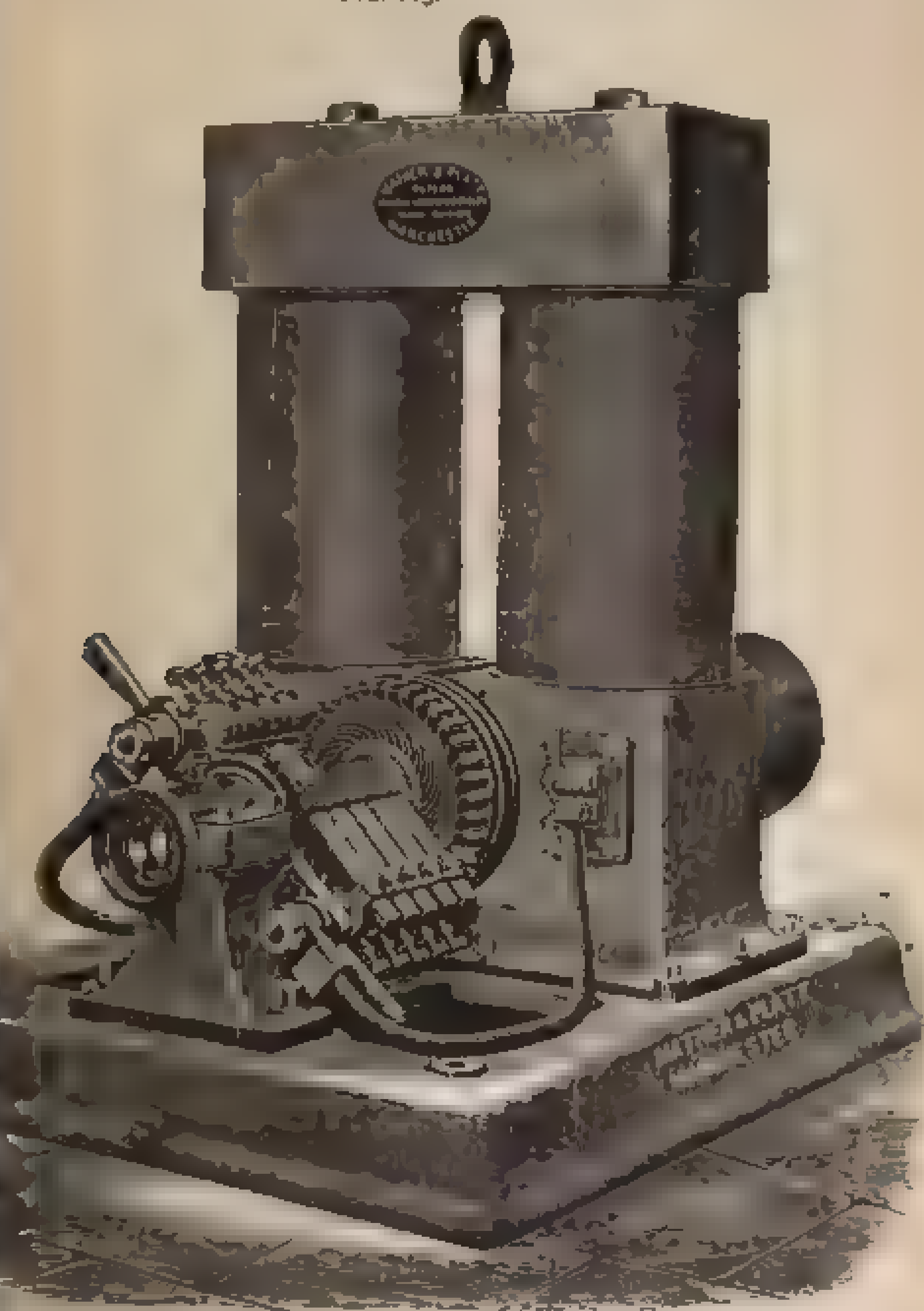
Therefore the magnetic indu
above referred to is about 18,
magnet 11,100 C.G.S. units.

Many forms of dynamo m
Mr. Edison. In some of the e
sisted of a number of straight e
divided into two sets, terminatin
between which the armature rev
was essentially bad, on account
quired as compared with the m
most economical form in this re

Since the laws which govern
better understood, Edison's fie

ally short-circuits the pole-pieces, and affords a path which some of the lines of force leak, instead of passing the armature. On the other hand, there is the advantage centre of gravity of the moving parts is kept low, thus

FIG. 185.



o the stability of the machine, and also in some cases facilities for driving direct from a steam engine fixed upon bed-plate. In the machine under notice this leakage is

revolutions per minute, develops an E.M.F. [illegible] maximum output being 12,000 watts. The [illegible] mature when cold is 0.045 ohm and of the sh[illegible]

The sectional area of the [illegible] the ar[illegible] in., and the maximum magnetic induction th[illegible] lines, while the sectional area of each limb of [illegible] 67.5 sq. in. and the magnetic induction thro[illegible] lines.

The unit of magnetic induction here referre[illegible] by Mr Kapp, who considered it more suitab[illegible] poses than that based on the C.G.S. system. [illegible] equal to 6,000 C.G.S. lines, and the unit of ar[illegible] square inch instead of the square centimetre. [illegible] perhaps, in some respects, unfortunate; bu[illegible] probably survive, as it is already used by the [illegible] manufacturers. The conversion from one syste[illegible] of course, be accomplished without much la[illegible] that one square inch contains about 6.45 square [illegible]

Therefore the magnetic induction through [illegible] above referred to is about 18,600, and that [illegible] magnet 11,100 C.G.S. units.

Many forms of dynamo machines have b[illegible] Mr Edison. In some of the earlier ones the [illegible] sisted of a number of straight electro-magnets [illegible] divided into two sets, terminating in a pair of [illegible] between which the armature revolv[illegible] was essentially bad, on account o[illegible] quired as compared with the m[illegible] most economical form in this resp[illegible]

Since the laws which govern el[illegible] better understood, Edison's field m[illegible] provided with single massive cores; [illegible] provement made on the machine wa[illegible] in fig. 185 is illustrated the latest form [illegible] dynamo. It [illegible] the machine [illegible] the armatur[illegible] lower end [illegible] an arrange[illegible] ne wa[illegible] which has t[illegible]

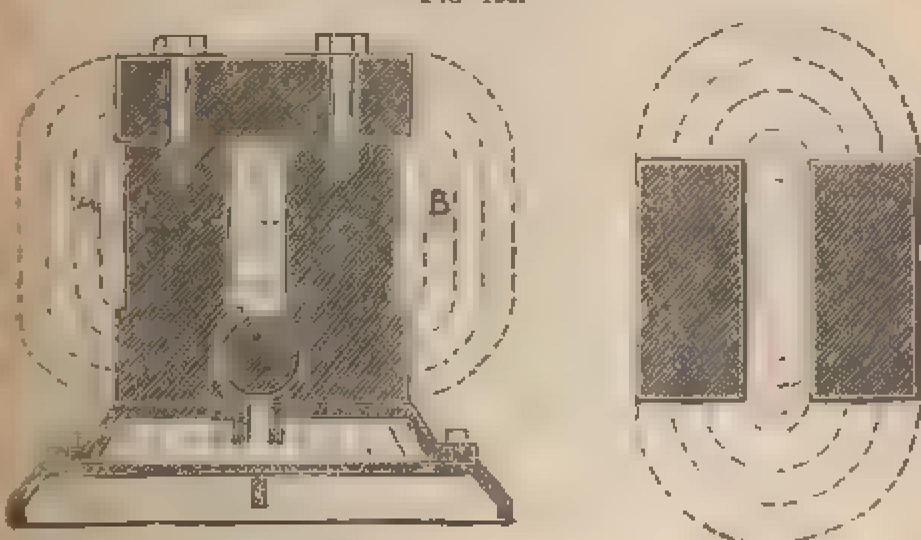
This type of dynamo is additionally interesting from the fact it has been carefully studied and tested by the Drs. Hopkin-, the results having been published in various papers. The ect was (*a*) to endeavour to gain such information as would ble the performance of a dynamo to be predicted, when its figuration and the various dimensions and qualities of the erial employed (especially the iron) are known; and therefore to enable any machine desired to give certain results at a ain speed, to be designed with the greatest accuracy.

We know that in every machine the magnetising force required develop the field in which the armature rotates is always in ss of that usefully employed; or, in other words, more lines of e are generated than actually pass through the armature core, difference being caused by leakage at various points.

We will briefly describe one portion of the experiments with view of enabling the student to better judge of the amount locality of such leakage in any given machine.

The portion of the experiments referred to consisted in the place of determining exactly the ratio of lines of force actually

Fig. 186.



erated, to the lines passing through the armature core. This o will of course always be greater than unity, and may be oted by *v*.

In fig. 186, a machine with rectangular cores is shown in ion, and lines of force are sketched to roughly indicate the

principal paths of the leakage. Some of the lin[es] from one limb to the other, others leak out of [the] pole pieces, while many pass through the arche[s] (on which the pole pieces rest), down into the iro[n]

We have previously mentioned that it is pos[sible ...] the number of lines of force cutting or cut by a [...] two or more given fields, by placing a galvano[meter] with the coil and observing the deflections. A[s the] E.M.F. is usually comparatively low, the galvano[meter ...] a delicate one, and it is usual to employ one in [which a] strongly magnetised needle is suspended by a sil[k ...] coil of many turns, the deflections of the needle b[eing ...] dent by the movement of a beam of light reflecte[d] by a small mirror fixed to the magnet. But in [...] necessary that the needle shall not begin to mo[ve ...] position until the whole of the brief current has [...] through the coil, and it is preferable to make t[he ...] and somewhat heavy, avoiding as far as possible t[he ...] of any damping effect. The number of divisions [...] velled over by the beam of light may then be taken [...] to the E.M.F. developed, and therefore to the n[umber ...] of force cut.

In the experiments under notice a current of [...] maintained through the field-magnet coils, from [...] armature being disconnected. A single convolu[tion ...] then wound round the middle of one limb as at [...] wire being joined to an instrument such as [...] and known as a ballistic galvanometer. The[n ...] the field-magnet coils were short-circuite[d ...] ping the current in them, and the lines of [...] the single turn of wire an[d] induced [...] passing through the galvan[om]eter, defle[cting ...] a moment. The needle [...] the short-circuiting con[...] suddenly passing the curr[...] of force in springing outw[...] [cu]rrent which deflected th[...] [th]e opposite direction to[...]

he mean of the two deflections was 264 divisions, which, the small amount of residual magnetism, may be taken ional to the induction in, or the number of lines of force rough, the field-magnet limb. The next step was to what proportion of these lines passed through the which was of the drum type, each coil consisting of one n only.

ires leading from the galvanometer were soldered one to o adjacent commutator bars, and the armature placed so ane of the coil connected to those bars lay at right angles s of force.

ield-magnets were excited as before by a current of es, and the deflection noticed first when the current in stopped by short-circuiting, and again when the current ound them a second time, so as to suddenly withdraw lines om, and then to thrust them through the armature core. of these two deflections was 200 divisions, and therefore

$$\frac{\text{ction through field magnets}}{\text{ction through armature}} = \frac{264}{200} = 1{\cdot}32 = \nu.$$

o say, 24·24 per cent. of the total number of lines of rated failed to reach the armature core owing to leakage. this method does not give us the actual number of lines a C.G.S. units, it nevertheless gives the proportion cor- l in these experiments the number passing through the was estimated in C.G.S. units by running the machine n speed and measuring the resulting E.M.F. without current to pass through the armature and distort the en the actual number of lines in any other part of the circuit could be found by simple proportion. Having at 24·24 per cent. of the lines of force were lost by he next step was to localise that leakage, that is, to t what points it occurred. This time the galvanometer, sensitively adjusted, gave a mean deflection of 115 with one turn round the middle of one limb, when a 5·6 amperes through the field-magnets was suddenly d stopped as before. Four convolutions were then nd the bed-plate directly under the armature shaft, and,

the current being stopped and started in the field magnets, the galvanometer indicated a mean deflection of 50·25 divisions, due to the lines of force which leaked through the bed plate and cut the four convolutions wound round it. Four turns were employed in order to get a fairly high deflection. The induced E.M.F. being, however, four times that which would be obtained with one turn, it becomes necessary, to enable this result to be compared with the previous one, to reduce it to the value of one convolution, thus:

$$\frac{50{\cdot}25}{4} = 12{\cdot}6 \text{ divisions, nearly.}$$

The leakage through the space between the field magnet limbs was measured with a coil of ten turns wound on a square frame, and by a similar calculation was found to be proportional to eight divisions with one convolution.

The horns of the opposite pole pieces approach each other both above and below the armature to within 12·7 centimetres, the depth of each being 8 centimetres. The leakage across each of these gaps was found to be 1·6 divisions, or 3·2 divisions for the two. Reducing these losses to percentages of the total induction, we have

The leakage through the zinc plate and iron base . .	= 10·3 per cent.
The gaps between the horns account for	2·8 ,,
And the area between the limbs	7·0 ,,
Making a total loss accounted for .	20·1 ,,
Out of an observed loss of . . .	24·24 ,,

The leakage through the shaft and from pole piece to yoke, and one pole piece to the other by exterior lines will account for the remainder.

This ratio, ν, will, of course, vary slightly with different exciting currents in the field magnet coils, especially when the iron approaches the saturation point, because, the permeability of the iron decreasing with the induction through it, while that of the air remains constant, the proportion of leakage will be greater.

These experiments constituted the first definite attempt to discover the extent and the locality of the leakage of lines of force

generated by the current in the field magnet coils, and it will be seen that almost a quarter of the power spent for the purpose of developing the field in this particular case was wasted. The large proportion of the leakage for which the bed-plate accounts shows the great advantage pertaining to the inverted horse-shoe form of field-magnet. It is to be regretted that the other types of field magnet which are now extensively employed have not been subjected to similar experimental examination, but a study of these experiments, together with those made in connection with the machine next to be described, should enable the student to make a very fair estimation in any ordinary case.

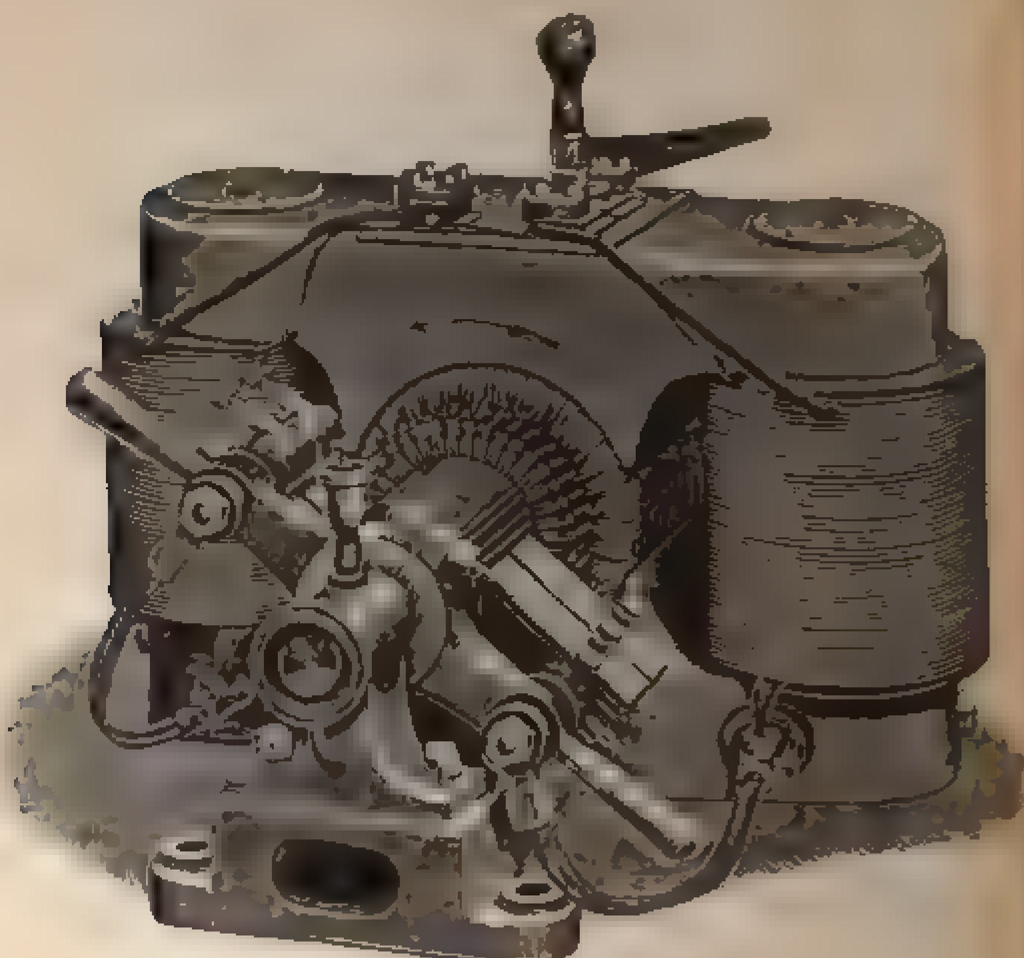
It would, for instance, be safe to predict that for a given magnetic saturation of the iron, comparatively little magnetic leakage would take place with the machine depicted in fig. 175, for the brackets are made of gun metal, and, excepting the shaft, there is practically no magnetic metal employed which would tend to increase the leakage. In this respect this machine is probably the best of any we are acquainted with; but we may again remark that the amount of leakage also depends largely upon the degree of saturation of the iron, and upon the magnetic resistance of the whole magnetic circuit. On the other hand, it would be false economy to make the leakage extremely low, if the extra expense incurred in so doing were out of proportion to the cost of the power which would otherwise be wasted in the generation of the field.

The 'Manchester' dynamo, made by Messrs. Mather & Platt, is illustrated in fig. 187. The arrangement of the field-magnets differs somewhat from that in the machines hitherto described. Two electro magnets are fixed vertically with their like poles uppermost, the similar poles being in each case joined together by massive iron yokes, shaped as shown, so as to form the pole-pieces between which the armature rotates. The lines of force due to the field-magnet coils are thereby provided with an easy path for completing their respective circuits, and an intense field is projected through the armature. The vertical members of the field magnets are of wrought iron, let into the horizontal yokes, which, being of cast iron, have about twice the sectional area of the cores. The lower casting is extended on both sides so as to form the bed plate of the machine, and the centre of gravity of the moving

parts being low, it is comparatively easy to rigidly fix the machine in order to obtain great steadiness in running.

The shaft carrying the armature is made of Bessemer steel, the bearings being of gun-metal, and a free space along the shaft is provided to admit air for ventilating the armature. When driven at 1,100 revolutions per minute, the machine illustrated, which is

FIG. 187.



compound-wound to maintain a potential difference of 100 volts, is capable of generating a current of 80 amperes or a maximum output of 8,000 watts.

The commutator in all dynamos of this type consists of forty bars of hard drawn copper insulated with mica. Each arm of the rocking-bar carries two brushes, each brush being independently adjustable for the reasons already explained. The diameter of commutation with machines of this class, in which the direction of the lines of force through the armature is vertical, approximates

the horizontal, and this position in the Manchester machine is re nearly approached in consequence of a peculiarity in the vature of the pole-pieces. Instead of the polar surfaces being de concentric with the armature, they are struck from a radius eater than that from the centre of the shaft, so that the pole-eces are brought slightly nearer the armature at points opposite e extremities of its vertical diameter. The lines of force are erefore more concentrated at these places, which reduces the stortion, and, increasing the activity of the most active or vertical ils, decreases that of those near the neutral point.

The armature is of the ring type, the core consisting of the ual thin iron discs clamped between the ends of a gun-metal ame. The arms of this frame, which fit into slots in the discs, e free of the shaft, so that a clear space for ventilation is re-ined. The end-plate nearest the commutator is keyed to the aft, while the other is held up tight against the plates by means a nut. The wire is wound in forty pairs of coils, the resistance om brush to brush being 0·084 ohm.

The shunt coils on the field-magnet have a resistance of ·5 ohms, and the series coils, which are wound outside the shunt ils, have a resistance of 0·049 ohm.

The gross weight of the machine is $10\frac{3}{4}$ cwt.

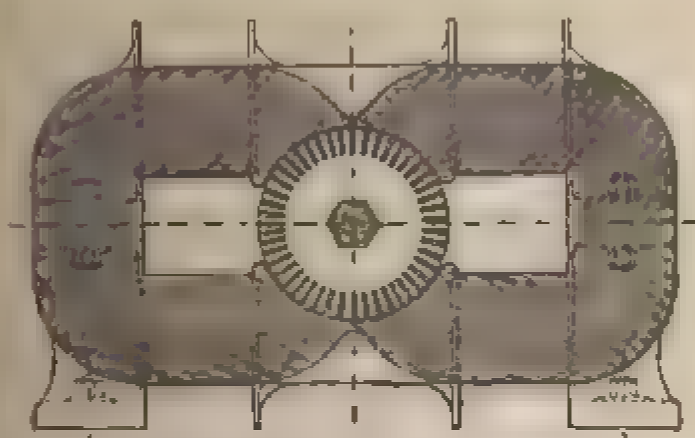
The brothers Hopkinson also made on this machine some periments similar to those already described, and we may briefly er to the simpler of the experiments which show the percentage d the locality of the leakage of the lines of force. Fig. 188 gives outline of the machine, and shows the various positions of the ting-coils. As in the other experiments, the armature was dis-nnected, and a constant current obtained from an independent urce to magnetise the field-magnets, the lines of force being de to cut the testing-coil by suddenly starting and stopping the rrent in the field-magnets, and the mean of the two observed flections of the ballistic galvanometer calculated as before. In e first experiment four turns were taken round the middle of e limb at A A, and the mean deflection was observed to be 214 visions. But as with a single turn of wire only one-fourth of s would have been obtained, $\frac{214}{4} = 53·5$ represents the total in-

... between each of ... armature derived b... teeth ... type of arm...

bviated by employing a large number of teeth and making nce between them very small, so that the oscillation of the ery slight—indeed, practically imperceptible. One section mature is wound in each slot, which is just wide enough a single insulated wire, and deep enough to hold the of wires in each section.

e armature shown in fig. 190 each section consists of six ions, so that there are six wires in each slot. If the slots de too deep, some of the lines of force would not be cut nner wires; in the present case, the number thus missed mall, practically none being lost in armatures having but s in each section. The core is built up of thin discs ron, of the shape shown in the sectional figure. The

FIG. 190.



oles are hexagonal, and the plates or discs are threaded e hexagonal steel shaft, so that each one is driven direct This, added to the fact already mentioned, that the wire l in deep and narrow slots, makes the armature as a whole cally strong, there being little risk of a sudden stress the core or stripping the conductor from its place. There nsually large proportion of iron in the core; in fact, the the space, except the small amount taken up by the insu- aterial, is occupied by the iron plates and steel shaft, no e whatever being made for ventilation. It will be observed, that a large amount of the iron core (the edges of the in direct contact with the air, and as the armature rotates

the heat is carried off by convection, thus preventing any rise in temperature. The facility afforded in this way for dissipation of the heat generated in the core, gives to Pacinotti ring one very important advantage. The commut sections or bars are insulated with mica, rings of asbestos fibre being employed at the ends of the bars to insulate t from the clamping-nut and washer by which they are hel position.

When the machine is compound wound, the series turn usually wound on the top magnet cores. Should the series not occupy the whole of the wire space, it is filled up with a tion of the shunt wire, which also occupies the whole of the s on the lower magnet cores.

For large machines, sheet copper, insulated with strips of c is used for the series winding.

The following details concerning one of these machines recently constructed to give 12,000 watts at an E.M.F. of 100 when driven at 710 revolutions, will be of service.

The armature is wound in fifty-two sections, each of tw volutions, so that there are fifty-two bars in the commuta two wires in each slot. The sectional area of the cast ir magnet cores is considerably greater than that of the a core, the former being 98 and the latter 29·7 square inche maximum magnetic induction through the armature core i 23 Kapp lines per square inch, or about 21,000 C.G.S. l square centimetre.

The armature conductor is of braided wire, very c insulated from the core and from the adjacent wire in th slot, and the current density in the conductor, with 126 a is 3,210 amperes per square inch.

The series winding on each of the top limbs consists of eight turns of sheet copper, 4·5 inches wide and 0·025 inc having a resistance of 0·0124", and giving, with the m current, 3,360 ampere turns.

The resistance of the shunt coils is 32·4", the ampere h the potential difference of 100 volts, being 6,468.

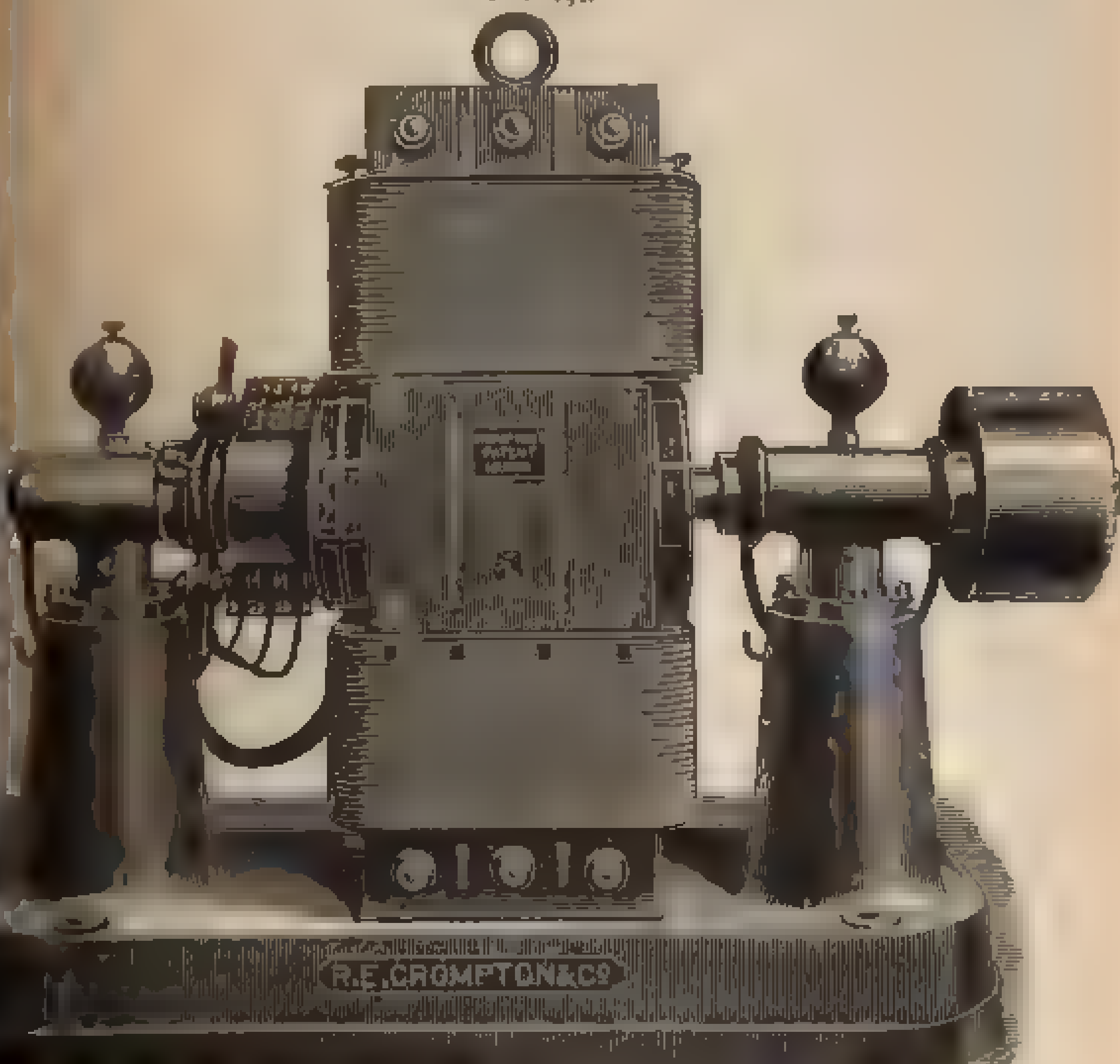
e may from the above easily determine the number of ded in the various parts of the circuit, remembering th

amount developed in the external circuit when the maximum current is being obtained will be EC = 100 × 120 = 12,000 watts. Thus,

Shunt coils	32·4Ω,	watts lost with	100 volts	= 308
Series „	0·0124Ω,	„ „	120 amperes	= 178
Armature „	0·045Ω,	„ „	120 „	= 648

Fig. 191 illustrates the 'Trade' dynamo of Messrs. Crompton & Co. It is somewhat similar to the Manchester dynamo, and to

Fig. 191.



that just described, in that it consists of a double electro-magnet, the difference being that it is fixed vertically instead of horizontally. The field-magnet cores are of annealed wrought-iron, and are

[illegible] the [illegible] bed plates. The [illegible] in such a manner [illegible] have their similar [illegible] north poles [illegible] poles adjacent, so that the [illegible] through the armature from and [illegible] between the coils, which [illegible]

[illegible] with a ring armature, in which [illegible] varnished paper, the [illegible] the commutator is wound [illegible] grooves, into which [illegible] along the shaft [illegible] The [illegible] ends of these [illegible] The conductor is of rectangular [illegible] the outer circumference, [illegible] the [illegible] driving bars [illegible] from the core, to [illegible] circumference, and the armature [illegible] to prevent [illegible] on a [illegible] from the [illegible]

[illegible] that it is not possible [illegible] a constant current in the [illegible] can be [illegible]. Hence [illegible] have been [illegible]

ain the greatest difference of potential. From the negative to positive brush either way round the commutator, the potential adually increases in value, and if the negative brush were shifted, y, 20° forward, it would touch at a point of higher potential, and nsequently the *difference* between the two brushes would be re-ced. A like reduction would follow if the positive brush were ved forward, because it would then make contact at a point of ver potential; and in the third case the difference of potential ween the two might be decreased by giving them simultaneously greater angle of lead, until they would be at nearly the same ential when moved through an angle of 90°.

It follows that by merely shifting the brushes the potential ference at the terminals may be made what we please from the ximum downwards, and this method might be employed to vary pressure, and therefore the current, to suit the requirements of circuit. Thus the brushes might be set 20° ahead of their normal ition of no sparking—that is, where the difference of potential ween them is at a maximum and then, if the current became strong, the brushes could be shifted yet further ahead, thus re-cing the potential difference and also the current; while by mov- the brushes back towards their normal position, the current could increased in strength, should it fall below the desired value.

This would, however, be impracticable in an ordinary dynamo, account of the terrific sparking which would ensue; and one of principal features in Mr. Statter's machine is the method by ich he renders it possible to vary the lead of the brushes through considerable angle, without causing this sparking.

Confining our attention at present to the case of ring arma-es, it will be remembered that when a coil which is carrying the ole of the current generated in one half of the armature is rt circuited by the brush, the electro-magnetic inertia of the l, due to its self-induction, prevents the instantaneous cessation the current; and that even if the coil is commutated at the ment when its plane is exactly at right angles to the field and refore in itself inactive, yet there will be a considerable spark sed by what we may term the self induction current in the coil. this reason it is found to be necessary to give the brushes a ht extra lead so that the coil may begin to cut lines of force,

and have induced in it an opposing E.M.F. sufficiently strong to overcome the self-induction effect, and stop the current in the coil before the brush leaves its commutator bars. Now the weaker the field the greater is the extra lead required to obtain this opposing E.M.F. The extra lead also increases with the self-induction of each individual coil, while in the case of some armatures, having but one or two convolutions in each section, it is practically nil.

It must be remembered that this *extra* lead is not due to the distortion of the field, but is simply required to prevent the sparking which would otherwise result from the self-induction of the coils. Neither must it be forgotten that if the current is kept constant in strength, the E.M.F. thus required to be counterbalanced is the same whether the coil is short-circuited at 10°, 20°, or 30° ahead of the normal position. In an ordinary field the action on the coil increases with such rapidity as it leaves the neutral position, that the self-inductive effect is more than balanced, and there is a remaining E.M.F. opposite in direction induced by the field on the coil, which is then competent to cause sparking.

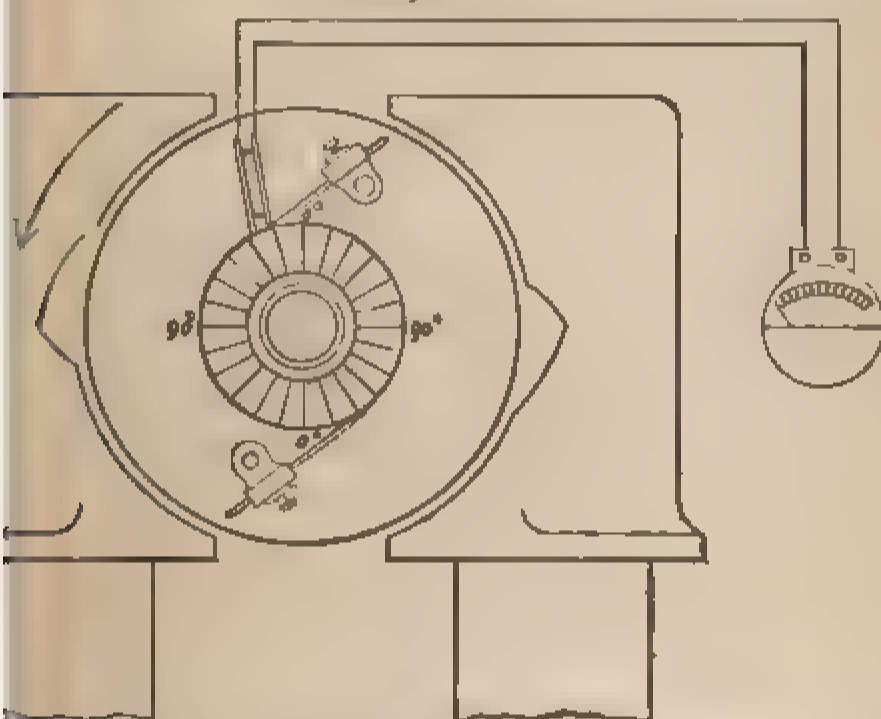
But if the field were made uniform and of such strength that for a certain distance beyond the neutral point—say through an angle of 40°—the number of lines cut by the coil at any point in that angular space was just sufficient to counterbalance the E.M.F. of self-induction, then the potential difference at the ends of the coil throughout that range would be *nil*, and no sparking would ensue if it were short-circuited.

This is Mr. Statter's method; and in order to allow a strong field to be employed, each coil contains an unusually large number of convolutions, there being also plenty of iron in the armature, so that a strong field is required to counterbalance the resulting high self-inductive effect. Portions of the pole pieces are cut away at such points as will make the density of the lines of force entering the armature over a given angle equal; and the exact places where the field has to be increased or reduced in strength are ascertained by experimenting in the following manner.

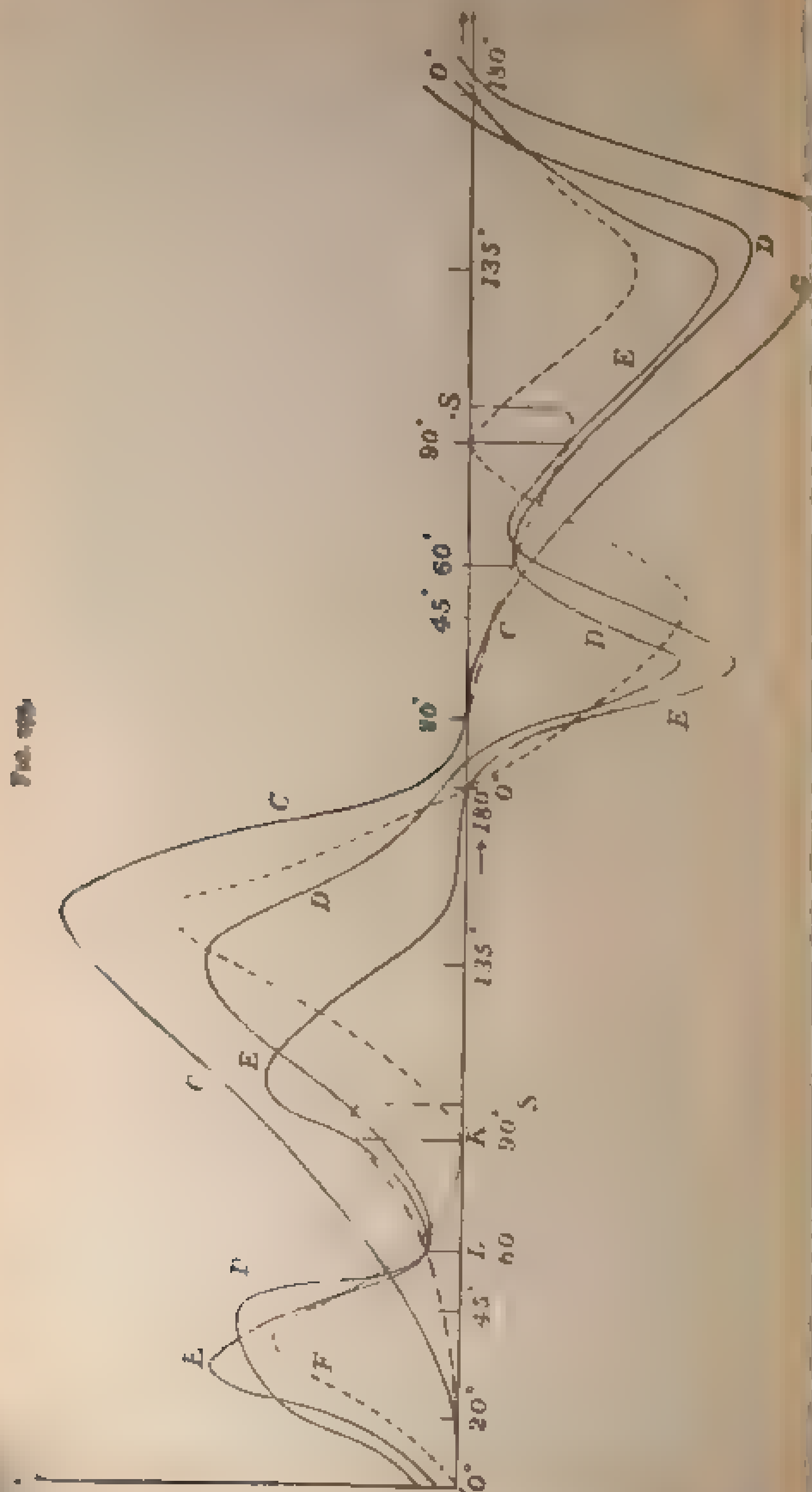
A series machine is constructed in the ordinary way, with pole faces concentric with the armature, but with a rather larger number of convolutions than usual in each armature section. The

[illegible]hich it is driven is kept constant, and also the current, [illegible]amperes, when the effect of self-induction, which has to [illegible]ed, but not over-balanced, will be constant also. The [illegible]s to find out what is the activity of a single coil at the [illegible]ges of its c[illegible]cular path, and, in order to decide this, use [illegible]f a set of apparatus which has been employed for dif[illegible]ects by other experimenters with good results. It con[illegible] voltmeter of the requisite range, having its terminals [illegible]y flexible wires to two copper strips, which are fixed at [illegible] distance apart by pieces of insulating material, so that

FIG. 192



[illegible] bridge over the width of a commutator segment. The [illegible]ent of this simple apparatus and the method of using it [illegible]ted in fig 192. While the machine is running, and [illegible] current through an external resistance, the exploring [illegible]s we may term them, are held against the commutator, [illegible]ed in the figure, and each coil as it passes the point [illegible] brushes are placed is connected up for a moment to the [illegible] which indicates the electromotive force developed in [illegible]while passing that position The exploring brushes are [illegible]suitable stages round the whole of the commutator, and


0°
20°
45°
60
90°
135°
180°
S
K
L
C
D
E
F
45° 60°
135°
90° S
0°
180°

the deflection of the voltmeter noted for each position. The results are plotted in the form of a curve (see fig. 193), the distances along the horizontal line being taken to represent the angular distance of the coil from the zero position on the commutator, while the vertical distances represent the E.M.F. in volts developed by one coil in the various positions.

The curve C C was obtained in this manner when the main brushes were placed in the normal position, the lead being about 30°. The results obtained in passing *down* the commutator in the direction of rotation are plotted above, while those obtained in passing *up* are plotted below the line; and it will be observed that the E.M.F. at the extremities of each coil becomes *nil* at 20° from zero, while it is a maximum at about 150° from zero.

To facilitate comparison, both the point vertically above and that vertically below the centre of the shaft are regarded as zero points.

This curve having been obtained, the brushes were shifted forward to a position 60° from zero, and, regardless of sparking, the potential difference at the extremities of a coil in all the various positions was again measured. Another curve, D D D, was obtained by plotting these results, and it will be observed that, at the moment a coil is passing under the main brushes, the potential difference at its ends is considerable. This potential difference, which gives rise to the sparking, is in fact proportional to the height of the ordinate L, and it is equal to the excess of the E.M.F. induced in the coil by the powerful field at this point over that momentary E.M.F. due to the self-induction of the coil at the moment it is short-circuited. It is clear, then, that to eliminate the sparking when the main brushes are given a forward lead of 60°, the strength of the field must be reduced by just so many lines of force as would develop an E.M.F. proportional to the ordinate L, and then the E.M.F. of self-induction and that being induced in the coil would exactly balance. The length and number of active conductors in each coil, and also the speed of rotation being known, this number of lines of force can readily be determined.

The main brushes were next given a lead of 90°, when, as might be expected, the sparking became even more severe, but by means of the exploring brushes and voltmeter the curve E E E was

rapidly obtained. The E.M.F. in excess, which at this position of the brushes causes the sparking, is represented by the ordinate G, which gives a means of estimating the extent to which it is here necessary to reduce the strength of the field. About ten such curves were obtained with the brushes in various positions between 20° and 100°; but we have only given three of them in order to avoid a complex figure. From each point on the horizontal line corresponding to the angular distance of the main brushes from zero, a perpendicular is erected to cut the curve which was obtained with those brushes in that particular position (as we have observed, L and K are such ordinates), and by joining the tops of the whole of the ten ordinates the dotted curves starting at 20° and terminating at S are obtained.

The area contained between one of these curves and the horizontal line affords an indication of the amount of iron which should be removed from the corresponding pole face in order to weaken the field to the desired extent.

But since the very act of increasing the distance between the pole-face and the armature core at one point increases the density of the lines of force at another adjacent point, the areas only approximately represent the shape of the cavity required in the pole-face. For this reason the curves are, in practice, simply used as a guide to indicate to what extent the field requires reduction at the various parts, and the iron is removed to a rather less extent than is sufficient, so as to allow a margin for any error. Other curves are then obtained by means of the exploring apparatus, and a second approximation to the final result is arrived at, the process being again repeated if necessary. The dotted curve F was obtained with the brushes at 90° after the pole-face had been shaped and shows by its coincidence with the horizontal line at 90 that no sparking took place with the brushes in that position.

One method of modifying the field is to cut a groove in the pole face parallel to the shaft, after the manner shown in fig. 194, and it will be seen that the outline of the groove approximates somewhat to the dotted shaping curves in fig. 193.

The desired result may, however, be obtained by removing the iron in a variety of ways, such as boring holes in the pole-pieces, or even by using iron of different permeability.

ſave here considered the case of a ring armature machine, h the maximum number of lines which each coil can at time embrace is only half the total number passing through . But in the case of a drum armature the whole of the n at once be embraced and cut by a coil during half a m; it is therefore only necessary to 'explore' through nd the commutator, and plot the curves, say above the obtain one shaping curve. This will indicate approxi-he amount by which the whole field must be reduced, and e of the iron may be removed from one pole-piece, or each, as in fig. 192.

is manner, then, is it rendered possible for the brushes ifted through a considerable angle in order to vary the difference, and consequently the current strength, without ing sparking. It now remains to show the method by e brushes are automatically moved to the proper position e current varies. A view of the machine, with its auto-ulator, is given in fig. 194. In this particular case, two oves are cut in each pole face, but they do not extend to cheek, so that, in external appearance, it is similar to an machine. The solenoid shown in the front of the figure with thick wire, and is joined up in the main circuit, so whole current passes through it. Inside it is a core f a small vertical movement, its centre being below that lenoid. When the main current rises above its proper s core is sucked up, and throws into gear a simple me-which increases the lead of the brushes and so reduces nt; similarly, a reduction in the current strength allows o fall, when the mechanism is reversed, and the brushes wards the zero or maximum potential position.

bar which carries the brush-holders is placed, as usual, d of the bearing next the commutator, the collar, how-ng adjusted and the bearing oiled so that the bar can y. On the upper part of the collar is fixed a toothed which gears with a pinion on a spindle parallel to the ft; the other end of this spindle carries two ratchet-ach 5½ inches in diameter, but with their teeth set in directions The nearer of these ratchet wheels can be

power available in the external circuit is 12,900 watts. It is series wound, the resistances, measured when the wires were hot, being: armature, 8·79 ohms; field-magnets, 3·3 ohms; regulating solenoid, 0·57 ohm. There are sixty commutator bars, and the number of convolutions in each section of the armature is fifty four. The magnetic induction through the armature is 17 Kapp lines, or rather over 17,000 C.G.S. lines.

An interesting machine of this class is in use for generating the current for the Northfleet Tramway, where the motors on the various cars are placed in series, and the power required varies rapidly and considerably, while the current must be kept constant at 50 amperes. The maximum E.M.F. at the terminals is 450 volts, and the brushes are continually travelling backwards and forwards, the sparking being hardly noticeable.

Another type of dynamo, manufactured by the same firm, is illustrated in section in fig. 195, the section being taken vertically through the spindle. The machine is designed to be driven direct by a steam engine, which is built upon the same bed plate with it, and it is, consequently, calculated to develop the requisite E.M.F. at a low speed.

The framework is a hollow casting, well stayed with cross ribs, and cast solid at one part to form the yoke. The slabs forming the limbs of the field magnet are of wrought-iron, of the brand known as 'Kirkstall scrap,' carefully annealed, each finished slab weighing 8 cwt.; they are fixed on to the framework by two bolts passing horizontally through the solid part of the casting.

The armature is drum wound, having Pacinotti teeth, the core being made of thin discs of Swedish iron, punched out to the required shape, and effectually insulated one from another by thin asbestos tissue and shellac varnish.

A number of keyways are planed in the shaft, and corresponding horns or projections are stamped out on the inner edges of the discs, to fit accurately into these keyways, the shaft being also fluted between them so as to afford air passages under the discs.

To form the Pacinotti teeth, the outer periphery of each disc is punched symmetrically with respect to the inner horns, so that, when the discs are threaded on to the shaft, rectangular grooves

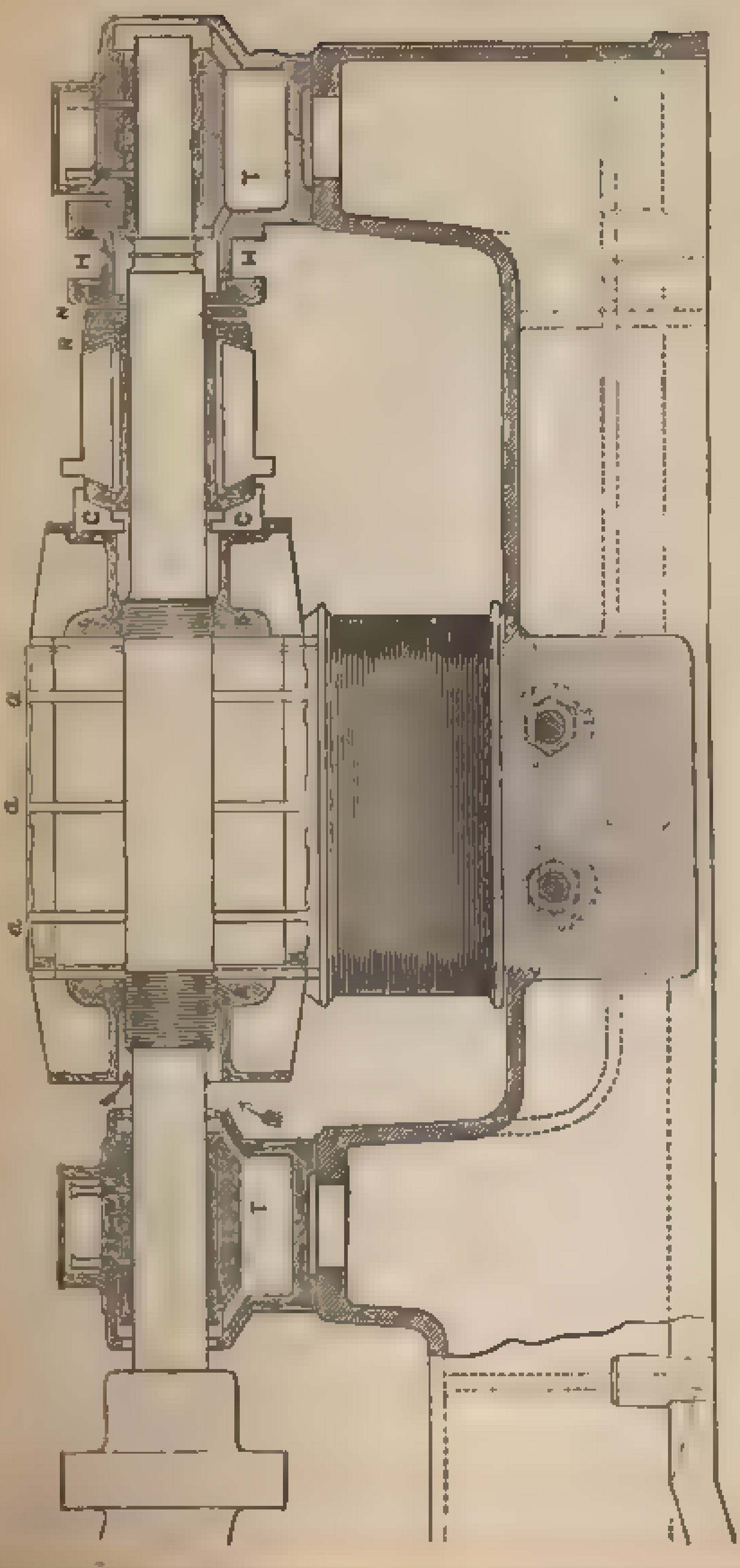


Fig. 135.

angles where it is best found
the discs upon the spindle, th
them. Fan-blades are set in th
plates are clamped together by
which are screwed upon the s
the end remote from the comm
municating with the flutings, p
and when the armature is rotat
the arrows under the end plate,
edges of the discs, and is forc
thus giving most efficient ventil

Fan-blades, C C, are also fix
commutator, at the back of whi
and prevent the accumulation
sixty bars in the commutator, e
connection with the armature co
these bars is also clearly illustra
for separating the bars from e
them from the bush and cone
The bush, which is keyed on to
order to obtain a higher pressure
made of wrought-iron instead of
with copper to prevent oil creep
each journal at T T, small tanks
groove in which the collar of the

in regard both to the armature and the field, is illustrated in fig. 196. It is known as the 'Victoria' dynamo, and is a development by Mr W. M. Mordey of a machine originally designed by Schuckert. In the earlier days of practical dynamo-building, engineers were much exercised by the comparatively large proportion of wire on ring armatures which cuts few or none of the lines of force, and which, therefore, is called idle wire. The Schuckert machine was designed to minimise this as much as possible, by flattening the armature ring, and extending the pole-pieces so as to make them embrace more of the wire on the flattened sides of the coils. The arrangement did not, however, altogether answer the anticipations, for by merely extending the pole-pieces, the density of the lines of force was diminished, and, with a magnet developing a certain strength of field, it matters little whether that field is spread out and the lines of force cut by a long piece of wire, or whether the field is more concentrated and only cut by a portion of the same wire.

This form of armature, even when the best shape is given to the pole pieces, is in reality slightly less efficient than either the ordinary ring or the drum form, but it is, nevertheless, a favourite, chiefly because it offers good facilities for ventilation, is very simple in construction, and (owing to the sectional shape of the armature coils) there is but little tendency for the wires to fly out when driven at a high speed. Flat ring armatures are also usually set to rotate in a 'multiple field,' that is to say, the field is generated by four, six, or sometimes eight poles.

Fig. 196 illustrates a four pole machine, four being the number most frequently employed. Each cast iron pole piece which partly embraces the armature has connected to it two cylindrical wrought-iron cores, the outer ends of these cores being bolted to the cast-iron standards forming the yokes.

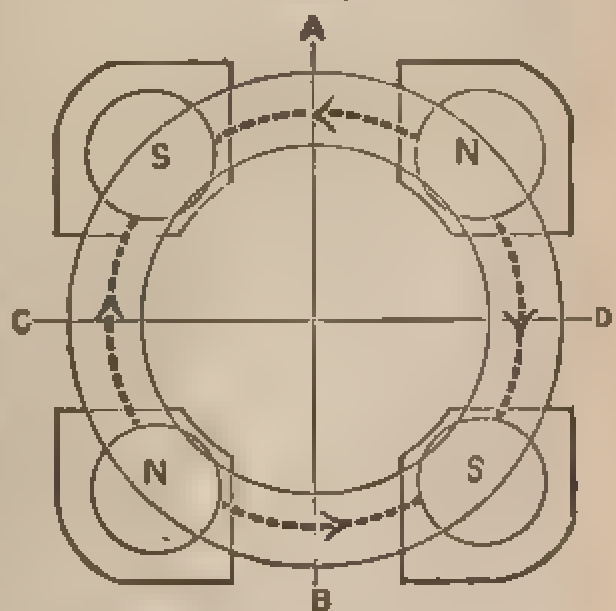
The two coils on each pair of cores are so wound that their similar poles are adjacent to the cast-iron pole piece between them, thus developing a strong field from the pole piece. These pole-pieces are magnetised in this way alternately north and south, the arrangement of the entire field being that shown in fig. 197, where the direction of the lines of force through the armature-core when it is at rest and the field undistorted, is shown by the

heads. The lines of force enter at the outer circumference also at both sides of the armature.

the diameter of commutation is at right angles to the of force, and as in this multiple field there are two such ters, A B and C D, two sets of brushes would appear to be ary. This will be more apparent if we consider the inductive effects upon a single coil during a complete revolution. Supposing the coil to start from A, where its plane is at right angles lines of force, its portion will, in approaching the pole-piece, N, lines of force from, and in passing from it will cut other lines, site in direction, from, the result being that induced current is in one ion only during the journey from A to D. the reversal takes for the coil, in approaching S, cuts these lines above, and, passing S, opposite lines from below, whence another continuous current is generated while the coil is travelling from D to B, where a reversal takes place; and similarly with the other quad- the third reversal occurring at C, and the fourth at A. Or, g the matter from another standpoint, since the reversal of current takes place at that moment when the maximum number of force is projected through a coil, and as this maximum at the point midway between each pair of pole-pieces (the being still undistorted), it will be evident that the current be reversed as the coil passes the points A, B, C, and D. fore, were the armature joined up in the ordinary way, one f brushes must be placed on the diameter A B and another diameter C D, to collect the current from all the coils.

avoid this inconvenient arrangement a simple modification in the winding. As every pair of diametrically opposite

Fig. 197.

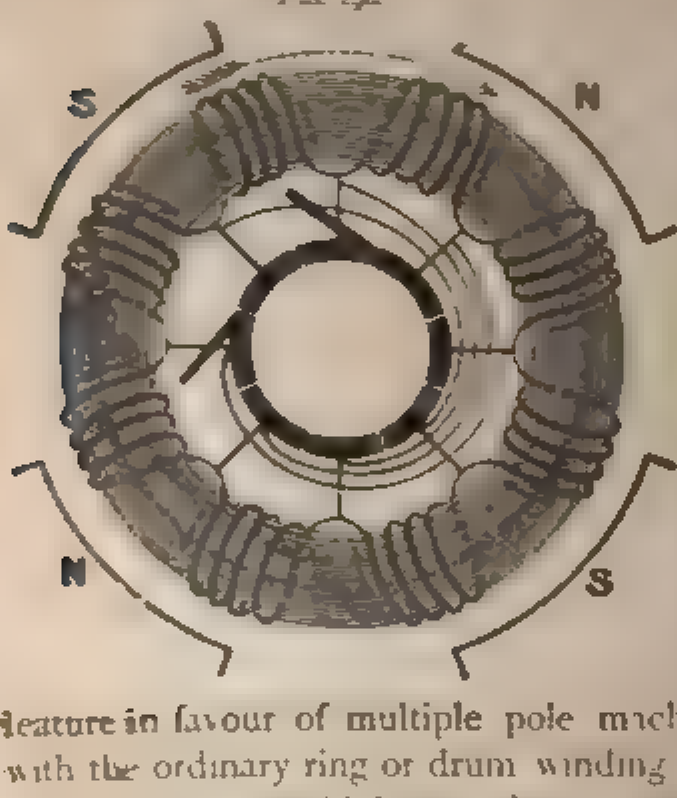


coils is at every stage undergoing precisely the same inductive effect as the pair of coils situated at right angles to it, it follows that every two such pairs of coils can be permanently joined together in parallel, for they are at every moment developing equal E.M.F.s. By this device only two brushes are necessary, one being set 90° ahead of the other.

The method by which this 'cross-connecting' is effected in the [illegible] machine practically consists in joining together the diametrically opposite commutator bars, as illustrated in fig. [illegible].

In this machine, as in every other, the reaction of the armature distorts the field and necessitates a forward lead being given to the brushes, which, however, are always separated by the same angle, viz. 90°. It must also be pointed out that there are always four paths open to the current through the armature, and that therefore the resistance from brush to brush is but one-sixteenth of what it would be were the whole of the coils joined in series. The low resistance thus obtained is an important feature in favour of multiple pole machines, for, in order to get with the ordinary ring or drum winding an equally low resistance, the conductor would have to be so massive that mechanical construction would be far less easy, and eddy currents would be generated in the conductor itself unless prevented by lamination.

Fig. [illegible]



In the case of a six-pole machine constructed on similar lines, either six brushes must be used, or, as is actually done, the commutator segments 120° apart, joined together in threes, two brushes being then employed with an angle of 60° between them.

In this class of machine, however, the adjacent pole pieces, being of opposite polarity, must not approach each other too

otherwise an unduly large proportion of the lines of force across the air-space instead of passing through the arma- d in any case the armature must be provided with sufficient make the magnetic resistance low. Special care must also n with the lamination of the armature core. It will be ered that the eddy currents induced in a rotating core, as other moving conductor, are at right angles to the lines of the field, and also to the direction in which the tor is moving. In the case of the ordinary simple-field , the lamination of the armature presents little difficulty as s of force enter it from the outside circumference only. pole piece *embraces* a flat-ring armature, and the lines of ter at the sides as well as at the circumference, and it is necessary to laminate the core in two directions, so as currents being induced either radially or in a direction to the shaft.

this reason an unusually large proportion of the space he coils of a flat ring armature is occupied by insulating instead of iron.

rring again to fig. 197, it will be seen that the direction of of force through the armature is, as it rotates, frequently , and that the number of reversals per revolution would be d by increasing the number of poles. Such changes in sation, if too rapid, would heat the core considerably, air the efficiency of the machine, and this is one reason re than six poles are rarely employed.

199 is a sectional side-elevation, showing the construction Victoria dynamo, fig. 200 being an end elevation, half in of the same machine.

core is built up by winding iron tape, 0·012 in. thick ut half an inch wide (with thin paper insulation), round a ght iron foundation ring, which is of the same width as the d core, and is slotted on both edges at four equi-distant The four-armed gun-metal spider S (fig. 200) is made in es, held tightly together by hexagonal nuts screwing on to , to which also the hub is keyed. A bolt likewise passes each of the arms, and when this divided spider is thus eld in position, a little projection from the outer extremity

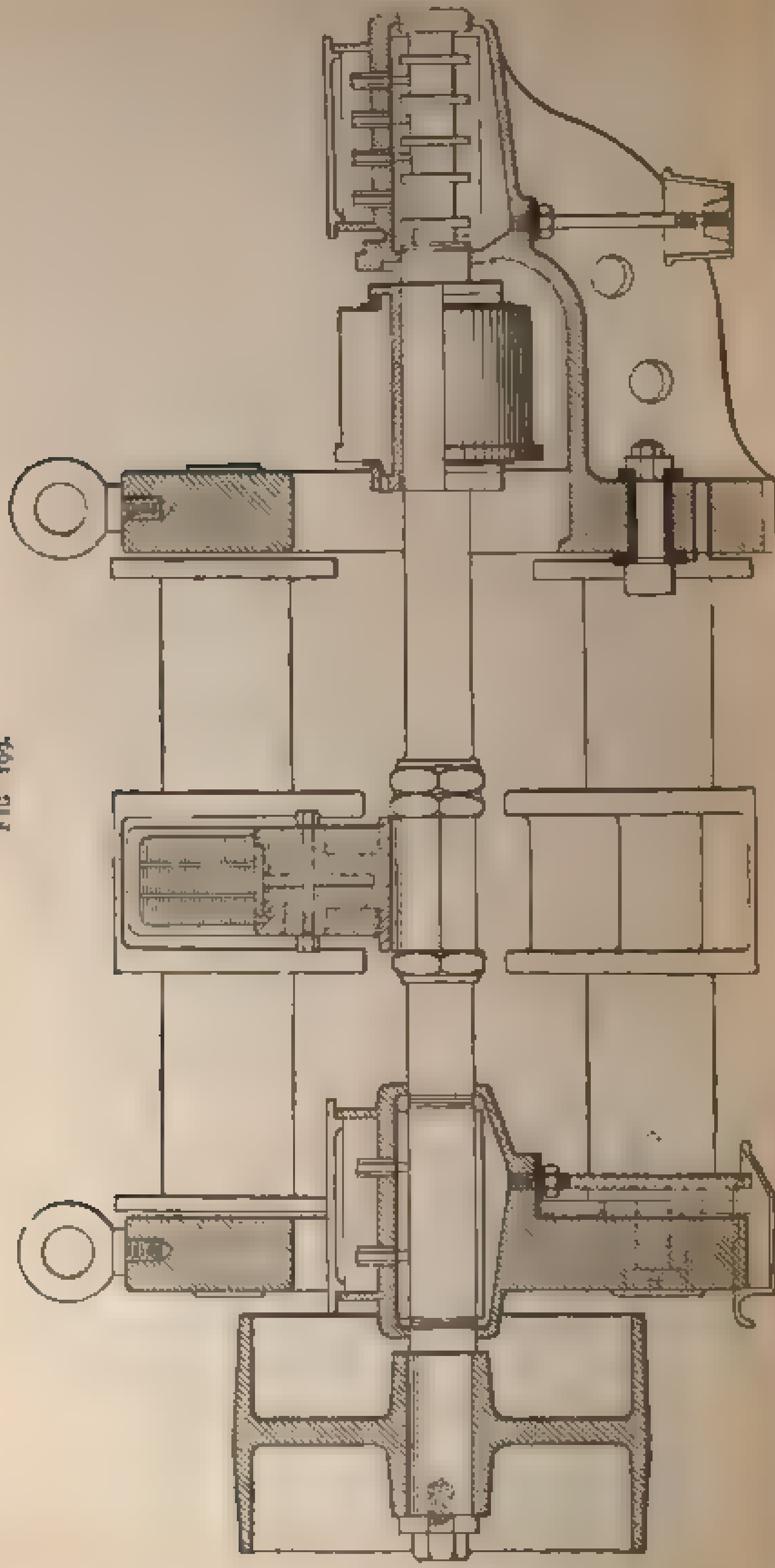
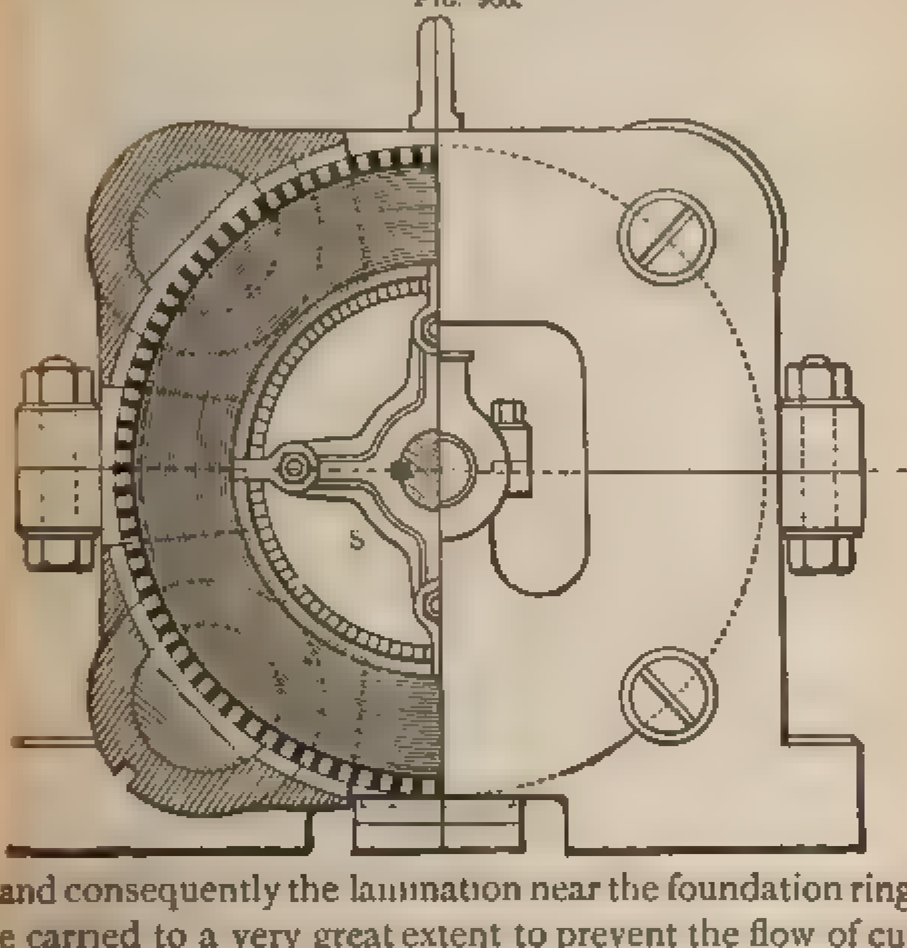


FIG. 199.

each arm fits tightly into one slot of the wrought-iron foundation g, and also extends a short distance into the core, a few of the er layers being slotted for the purpose.

The section of the core is rectangular, and its radial depth is siderably less in proportion than that of the early flat ring artures. Comparatively few of those lines of force which enter at outer circumference penetrate through the whole depth of the

FIG. 200.



e, and consequently the lamination near the foundation ring need be carried to a very great extent to prevent the flow of currents a direction parallel to the shaft. In some recent Victoria chines, the strips are, for this reason, narrower and more merous towards the outer circumference than near the inside.

The armature conductor is rectangular in section, insulated h tape, and is wound in one continuous spiral round the core, connections from the commutator bars being soldered on at proper points on the inside of the ring.

The armatures of the smaller machines are, however, wound h ordinary circular wire, cotton-covered and well varnished.

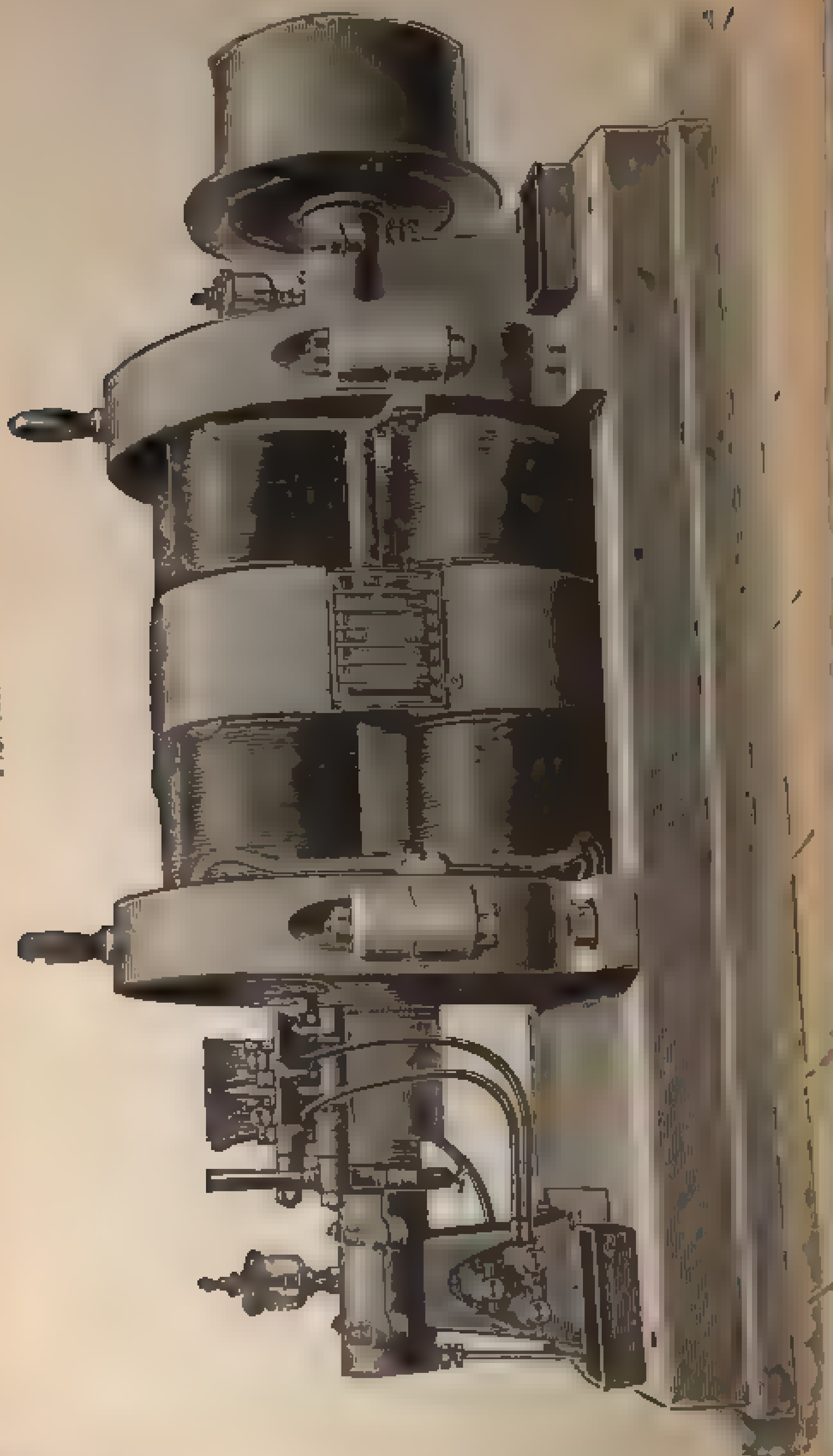


FIG. 601.

Each of the vertical standards forming the yokes is cast in two pieces, which are bolted together, so that the upper portion of each, with the two upper field magnets, can be removed to afford access to the armature. This arrangement is shown in the figures, from which it will further be seen that the upper part of the bearings can also be detached, thus enabling the armature to be easily lifted out of its position when necessary for examination or repair.

As in all other machines, it is necessary for the space between the field-magnet and the armature to be as small as possible, and since the pole-pieces extend over the sides of the latter, it is clear that there must be no end play, or shifting of the shaft lengthways; this is effectually prevented by the long-grooved bearing shown to the right in fig. 199.

These machines are series, shunt, or compound wound, as required. One built for the authors for educational purposes can, by means of a switch fixed on the top of the framework, be connected up for any one of these systems at pleasure.

The machine illustrated is intended to be driven at 1,000 revolutions per minute, and is then capable of developing 15,000 watts in the external circuit, at a terminal potential difference of 110 volts.

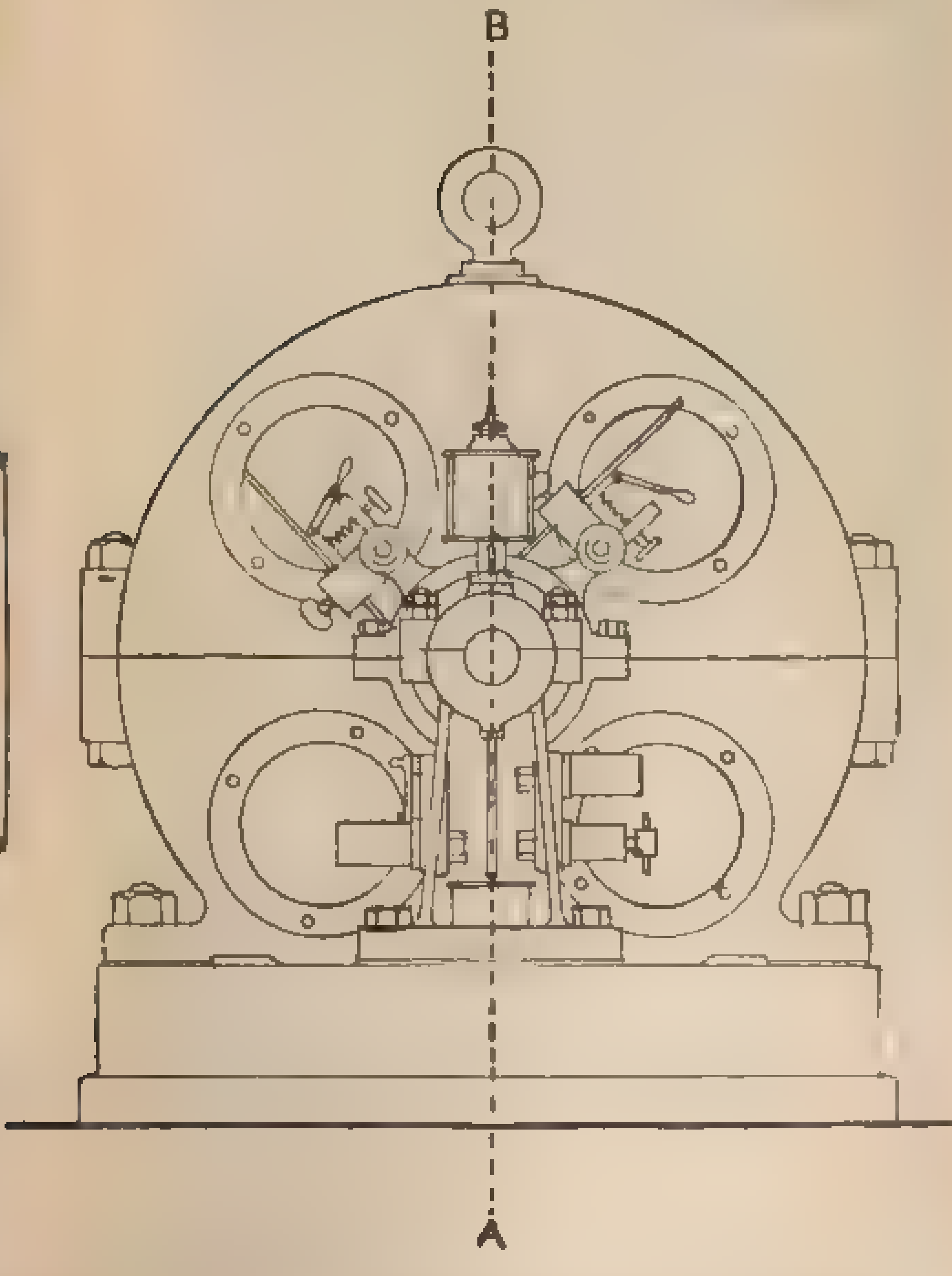
A multipolar flat ring machine is also manufactured by the Gülcher Company, and the latest type of this, known as the 'Battersea' dynamo (fig. 201), is worthy of special notice. As has been remarked, such machines, while slightly less efficient than other forms, present in some respects fewer difficulties in construction, and the Battersea dynamo is, from a mechanical point of view, as well as electrically, an exceptionally good specimen of its class.

Fig. 202 gives a longitudinal section through a machine of recent construction, a side elevation being shown in fig. 203. It is a four pole machine, having an output of 12,000 watts.

The foundation of the armature core is the rim of a strong gun-metal wheel, which has four radial arms. The hub of the wheel bears on one side against a collar on the steel shaft, as shown to the right in fig. 202; it is held tightly in position on the other side by a steel nut which screws on to the shaft. The core itself

insulation and the tightne
space to the lowest possible
The armature conducto
over this core (embracing al
a single layer; the strip is
being calculated so as to jus
circumference, and thus the
the core is made a minimum.
the current is collected from
apart. The method of conn
coils in parallel is unique.
and commutator is fixed a wo
flat copper rings are slipped.
and each has two lugs proje
diameter; a radial saw cut is
for a copper conductor strip to
rings are so arranged that t
shaft, and those connecting st
opposite coils of the armature
the lugs of the same ring. In t
of the commutator are joined
shown at the ring nearest the c
The circular cast-iron end
field-magnets are in two halve

FIG. 203. *To face page 374.*



consists of soft iron wire rectangular in cross-section, and insulated with cotton. It is wound round the foundation-ring under high tension, the core thus built up being very strong and rigid.

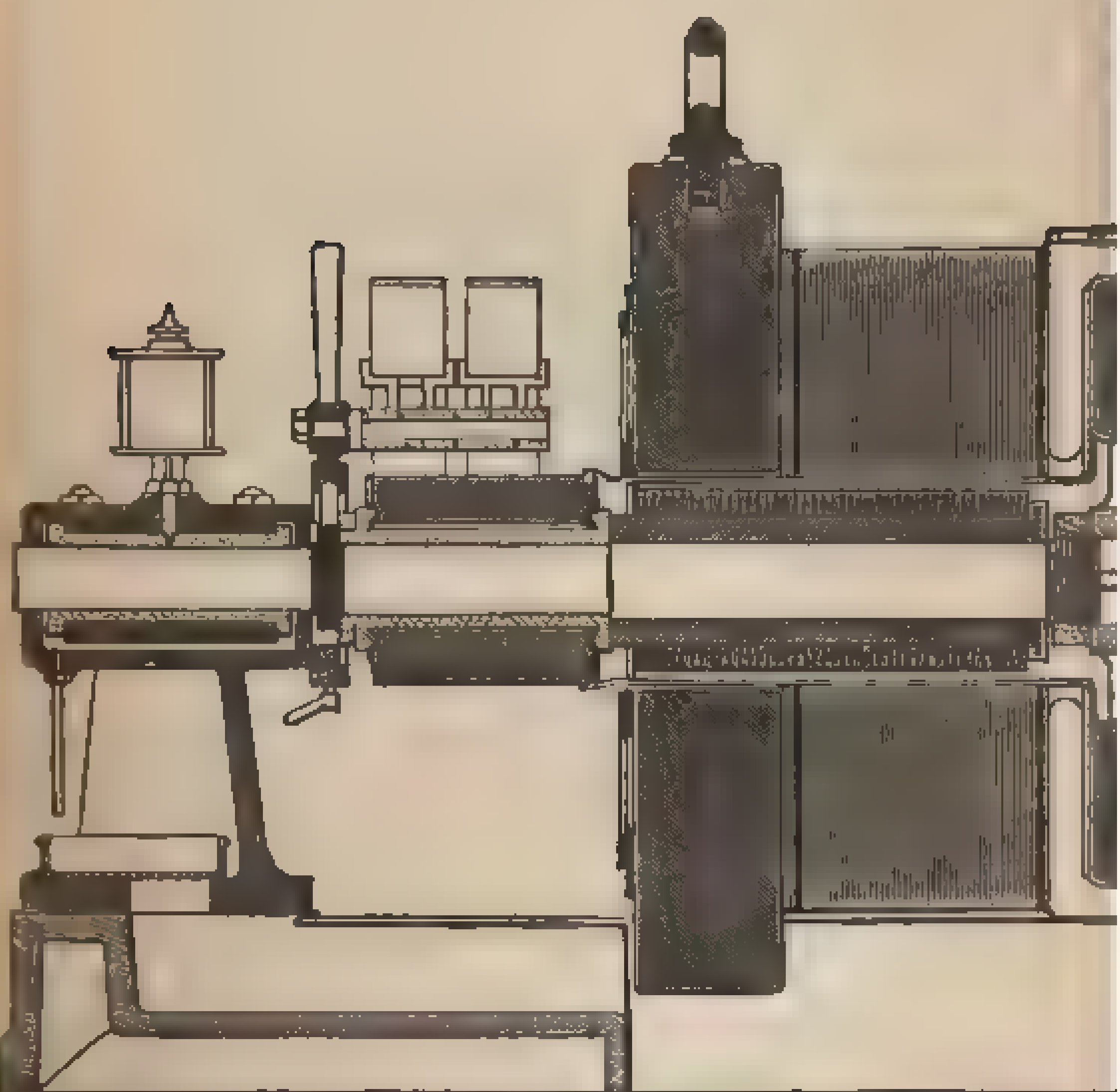
We have referred to the necessity for lamination in two directions; and the smallness of the wire, and the efficiency of its insulation practically eliminate eddy currents, while the thinness of the insulation and the tightness of the winding reduce the waste of space to the lowest possible limit.

The armature conductor, which is a copper strip, is wound over this core (embracing also the rim of the supporting wheel) in a single layer; the strip is rectangular in section, its dimensions being calculated so as to just occupy the allotted space round the circumference, and thus the distance between the pole faces and the core is made a minimum. By the device of cross connecting, the current is collected from a single pair of brushes, placed 90° apart. The method of connecting diametrically opposite pairs of coils in parallel is unique. On the shaft between the armature and commutator is fixed a wooden sleeve, over which a number of flat copper rings are slipped. These rings are carefully insulated, and each has two lugs projecting at opposite extremities of a diameter; a radial saw cut is made in each lug, just large enough for a copper conductor strip to be pressed in and soldered. The rings are so arranged that their lugs form a spiral round the shaft, and those connecting strips which lead from diametrically opposite coils of the armature to the commutator, are soldered to the lugs of the same ring. In this way diametrically opposite bars of the commutator are joined together; one such connection is shown at the ring nearest the commutator in fig. 202.

The circular cast-iron end frames forming the yokes to the field magnets are in two halves bolted together, the lower half being also bolted to the bed plate, as shown in the illustrations. These yoke pieces are very massive, and, as the surfaces of contact between them and the wrought iron cores are large and close-fitting, the magnetic resistance is low, and a large proportion of the lines of force are led into the armature.

The whole armature conductor offers but little resistance, and as, by the cross-connecting, this is reduced to one-sixteenth of the resistance which would be offered were all the coils joined in

FIG. 2



Sec

series, but little power is absorbed in the armature, and th machine is self-regulating through a considerable range.

The commutator consists of eighty copper bars, with mic insulation, fixed, as shown in the drawing, by a gun-metal nut an washer, over a gun-metal sleeve.

In smaller machines, circular copper wire, instead of rectangu lar strip, is employed for the conductor, and the magnetic resist ance of the core is even further reduced by covering the iron wir with silk instead of cotton, the former occupying much less spac than the latter.

In concluding this chapter, we may with advantage pass few further remarks concerning the losses which reduce the effi ciency of a dynamo. Omitting the power absorbed in overcomin the conductor resistance, which can easily be calculated, the losse may be classified under three general heads: (*a*) Mechanica friction; (*b*) Eddies in conductor; (*c*) Losses in armature cor The friction occurs principally at the bearings—for the commutat brushes should exert only just sufficient pressure to insure reliabl contact—and the loss due to this cause increases regularly wit the speed at which the machine is driven. When the conduct is massive, as in the case of a bar armature, the eddy currents i it may be sufficiently important to absorb a considerable amour of power, and, as we have seen, such conductors are frequentl laminated, or sometimes braided wire is employed, to preve the circulation of the currents. Lamination of the iron core, properly performed, also reduces to a minimum the eddies in th iron; but there is another source of loss which arises when lin of force passing through iron are rapidly reversed or altered i direction, due to a phenomenon known as hysteresis. This lo appears to be the result of a kind of internal friction between th molecules of the iron, when they change their position, as w believe they do, under the influence of the magnetising force. A any rate, it is not possible to project lines of force through iro or alter their position, without a small amount of work being pe med independently of that resulting in eddies.

With one particular specimen of iron, through which t agnetic induction was 18,000, Dr. Hopkinson estim ,000 ergs were expended in twice completely reve

CHAPTER XI.

DIRECT CURRENT DYNAMOS (OPEN COIL).

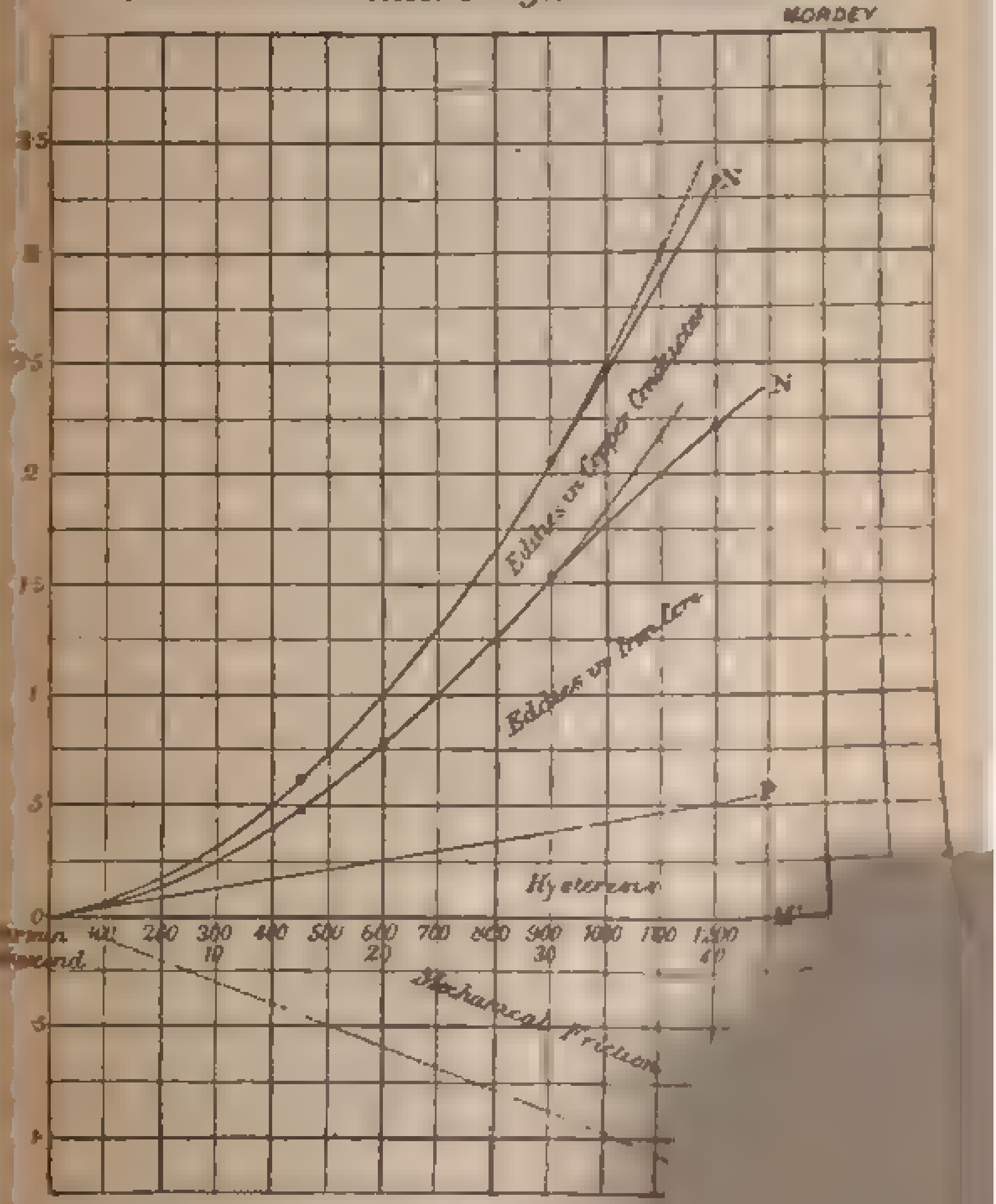
In the armatures of the direct-current machines hitherto described all the coils are connected together, and the junction of each adjacent pair is joined to a bar of the commutator. But there is another method of constructing an armature, in which the coils are kept quite separate, each having in the simplest form a separate two-part commutator. The former are known as 'closed-coil,' and the latter as 'open-coil' armatures. Machines for developing very high electro-motive force are usually built with open-coil armatures, an E.M.F. of 2,000 volts being not uncommon; hence such machines are used for electric lighting in cases where the type of the lamps and their disposition are such as to require the transmission of the current through a high resistance. In a closed-coil armature the E.M.F. generated by every coil in any and every position, excepting at the moment when it is short circuited by the brush, forms a part of the total E.M.F. of the machine. On the contrary, in an open-coil armature the current is collected from a coil while it is in the position of greatest activity only, or while the E.M.F. induced in it is at its maximum, the coil being thrown out of circuit during the time that it passes through the period of least activity. At the beginning of this latter period another coil enters the best position, and commences to feed the circuit. The coils may be wound either on the ring or drum principle, but in the former case the two coils at opposite extremities of a diameter are joined together in series and may be treated as one coil.

Many of the elementary principles examined in connection with the machines already described, hold equally well for those with open-coil armatures, and while it is unnecessary to again

On winding the armature and repeating the experiments, the curve O N′ is obtained, and the difference between the ordinates

FIG. 224.

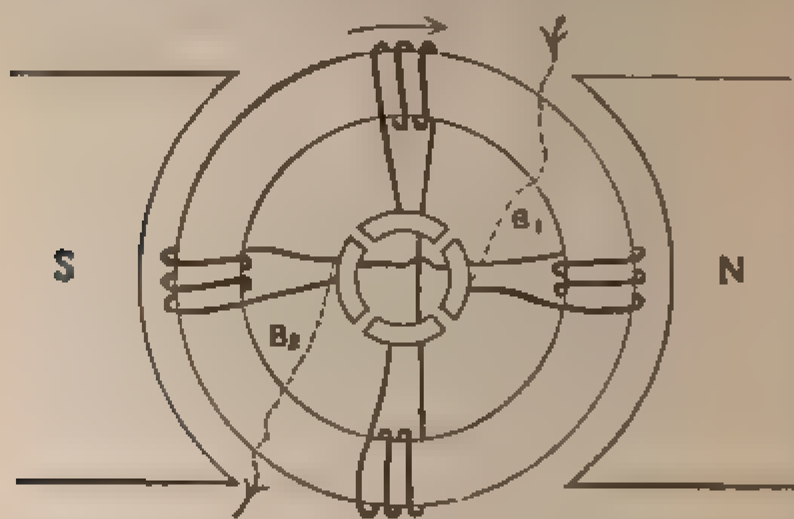
Determination of Losses in Dynamo Armature



N′ and O N represents the loss due to eddie[illegible]
conductor.

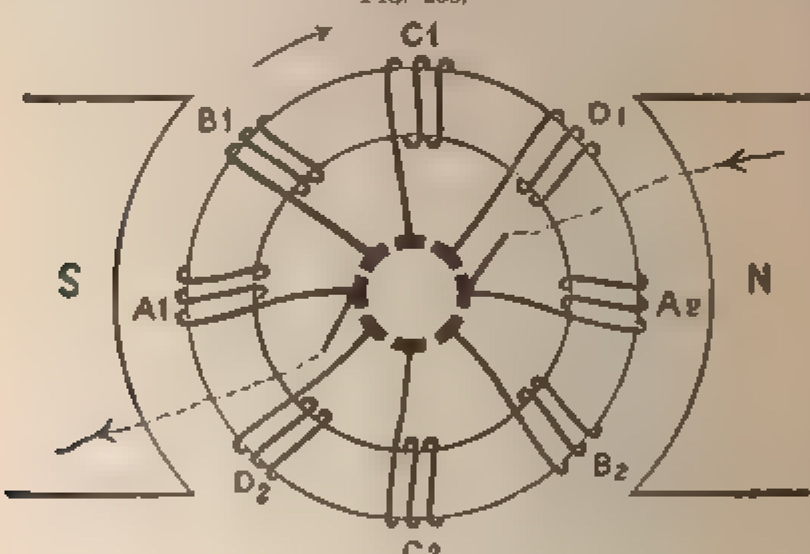
while the vertical ones, being comparatively idle, are entirely dis-connected. The activity of the horizontal pair decreases from this point, and when the armature has revolved through another

Fig. 205.



45° they are thrown out and the other coils begin to feed the circuit. Each pair is thus joined up and disconnected alternately for a period equal to a quarter of a revolution, and an ammeter placed in the external circuit would indicate a current, continuous

Fig. 206.

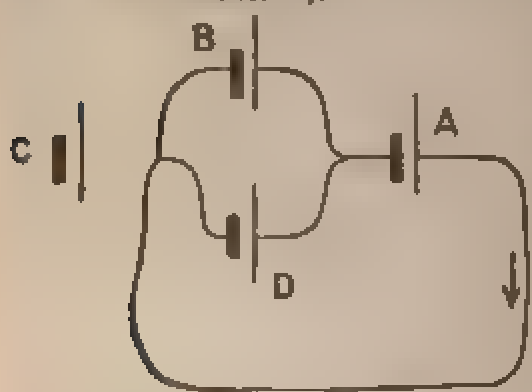


in direction, but fluctuating considerably in strength. Greater steadiness, that is to say, a nearer approach to constancy, can be obtained by increasing the number of coils, although it is not

possible to get a current so nearly constant as that which a good closed-coil dynamo can generate. In fig. 206 the number of coils is increased to eight, that is, four pairs. The two coils at opposite extremities of a diameter, A_1 A_2, for instance, are joined together to form a pair as before, but to avoid a complicated diagram this connection is not shown and the distortion of the field is again ignored. Each pair has its commutator, the segments of which are (including the insulating space between the adjacent segments) one-eighth of a circle, or 45° in length, and therefore each pair of coils is connected to the brushes for one-eighth of a revolution only. The maximum E.M.F. is the same as in the last case, and as the minimum does not fall so low, the resulting current is more nearly uniform. It will probably occur to the student that the coils D_1 D_2 and B_1 B_2, although far less active than A_1 A_2, are yet in a position where they can generate a considerable E.M.F. and that they might with advantage be allowed to assist. But they must not be joined up in *parallel* with A_1 A_2, since their E.M.F. is so much less. Otherwise we should get a result similar to that obtained when a Grove cell and a Daniell cell are joined up in parallel, that is, the Grove cell urges a backward current through the Daniell because it has a higher E.M.F., and the external circuit gets actually less current than if the latter cell were removed altogether. But if the two are joined up in *series* then the external circuit gets the whole current resulting from the sum of their two E.M.F.'s. In the same way, if the effect of the coils in positions of less activity is to be utilised, they must be joined up in series and not in parallel with those developing the higher E.M.F. We will explain how this matter is arranged in what is perhaps the best open-coil machine, viz. the 'Brush' dynamo. Now in the case of a set of four pairs of coils rotating in a uniform field, as in fig. 206, it is clear that at one time, only one pair of coils can be in the best, and only one pair in the worst, position for generating a current. On the other hand, it is possible for two pairs to be equally active in an intermediate position, and this will happen when they make an angle of 45° with the lines of force, that is, in the position occupied by B_1 B_2, and D_1 D_2. In the Brush dynamo, when the armature consists of eight coils, two pairs of brushes are employed, one collecting the

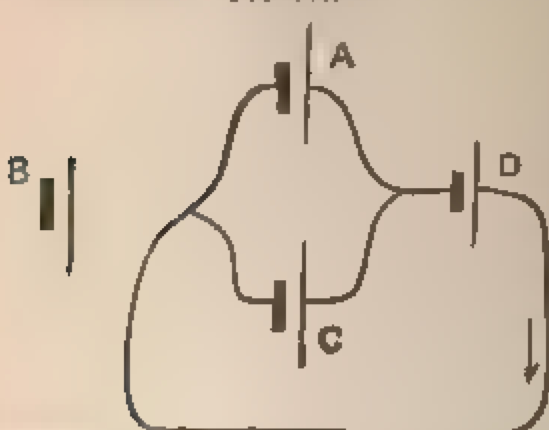
current from the coils in the best position only, A_1 A_2, the other joins up the two pairs of coils in the intermediate B_1 B_2, D D_2, in *parallel*, and collects the current from the two pairs of brushes are joined in series, and thus the the intermediate coils is *added* to that of the coils in position, only one pair, being thrown idle at As the intermediate placed in parallel their the same as that of one the resistance being, halved. In order to quite clear we may repr pair of coils as we do a cell, and then show the ment, as in fig. 207, where A represents the most active the least active pair of coils, B and D being those in the mediate stage. When the armature has turned through 45°, the B coils are idle, the D are at the maximum, and and C in parallel, as shown in fig. 208.

FIG. 207.



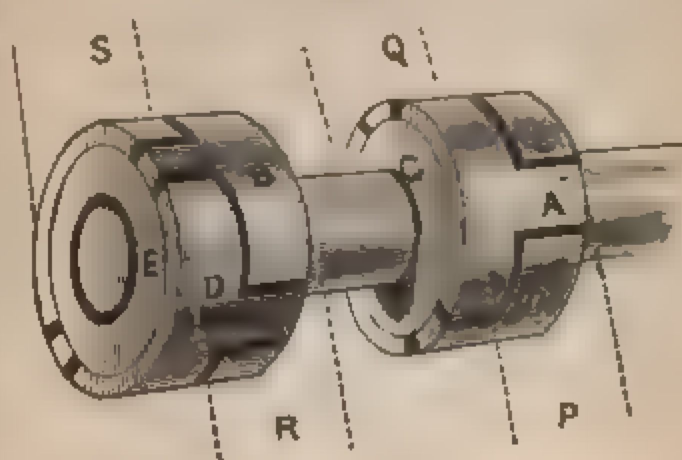
The commutator, by means of which these changes are is illustrated in fig. 209. It is divided into two portions complete in itself, and ing of four thick T-pieces of brass separated the shaft by rings of ins material, E G; the T-sections being insulated each other by air-spaces brushes, P Q R S, are fo flat copper strips, and, as by the dotted lines, are ciently wide to cover the width of the commutator rings. The ends of a pair of joined to diametrically opposite segments or sections as in in the figure, the lettering in this illustration correspond that in fig. 206. One of the commutator rings is fixed shaft 45° in advance of the other, the consequence of w

FIG. 208.



n one ring, each of the brushes is resting on one sec-
at A, then each brush on the other ring is in contact
ions, as at B, D. The student will perceive that in the
ed the sections of the left-hand commutator ring have
m the two
which are
ermediate
therefore
placed in
the right-
joined to
) which is
sition and
ir which,
re, is dis-

FIG. 209.

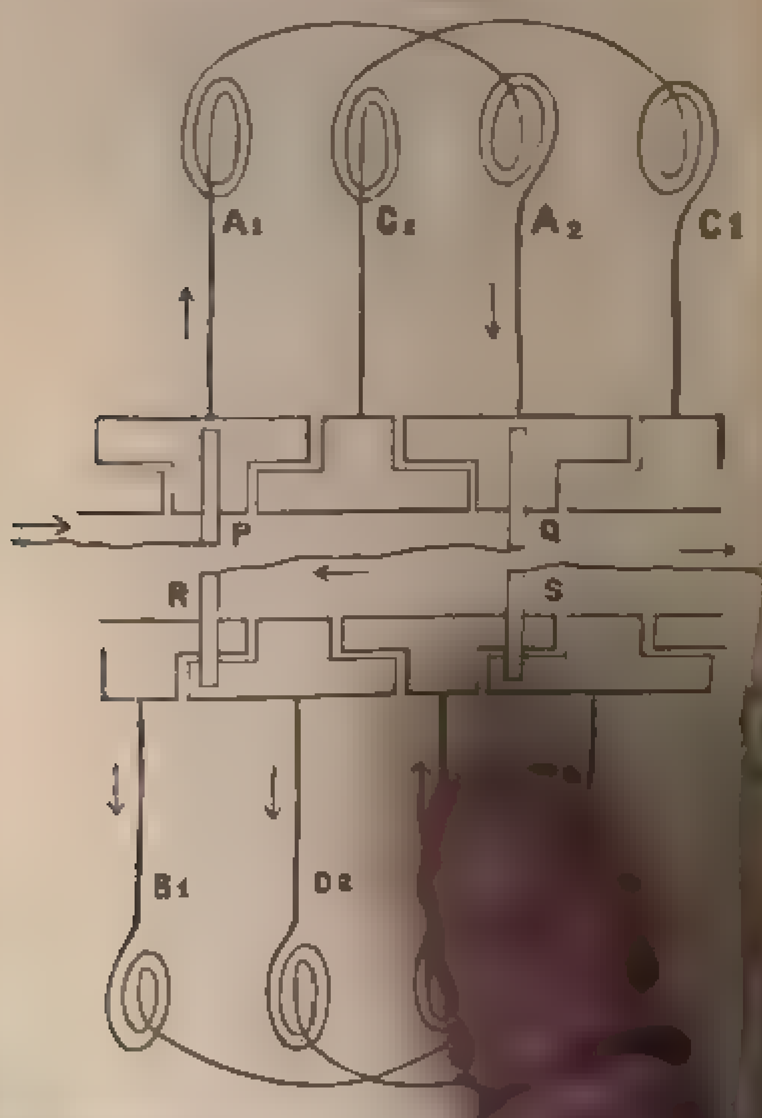


10 the two double commutators are developed or
ide by side, to make the matter clearer, the lettering
being the same as in fig. 206. The path of the
ily traced. It passes round the pair of coils, $A_1 A_2$,
and Q (by which it enters and leaves), each resting
n only, because those coils are in the best position.
hen passes direct to the brush R (on the left-hand
mmutator), which, resting on two sections, affords a
B_2 and $D_2 D_1$, in parallel. The brush S, by which
is connected to one end of the field magnet
ils C, C_1 are disconnected. Such is the action
ush dynamo having four pairs of coils in

picted in figs. 2[illegible] d 212, the latter
the commut[illegible] d. The cores
oblong in s[illegible] are securely
h form [illegible] These two
are [illegible] their similar
[illegible] round the
[illegible] on in the
[illegible] e the loss

The method of building up this core is illustr[illegible]
A thin soft iron ribbon is wound in a continuous [illegible]
iron foundation ring A^1. Between the successive [illegible]
the ribbon, and held by them as the process of [illegible]
carried out, are placed u shaped iron stampings, s, of [illegible]
ness as the ribbon. The connecting portion of [illegible]

FIG. [illegible]



lies wholly within the turns of the [illegible]
and forming spaces, as at B, with[illegible]
The [illegible] are all of one size, so [illegible]
port[illegible] are nearer to each [illegible]
tion, [illegible] of the channels [illegible]
are p[illegible] rigidly [illegible]

ted bolts, *b*, d radially h the H pieces, ral ribbon and ndation ring, shown in the al view The ngs and rib-ire, however, tionally much r, and the r of turns is more nume-an shown in ire. The loss ned by eddy s is thus re-o a minimum. e armature re insulated he core by of canvas and reated freely ellac varnish, ers of wire nsulated by cloth. The f each pair are carried the shaft to per sections ommutator. field magnet e also care-ulated from es by vul-fibre and paper, the

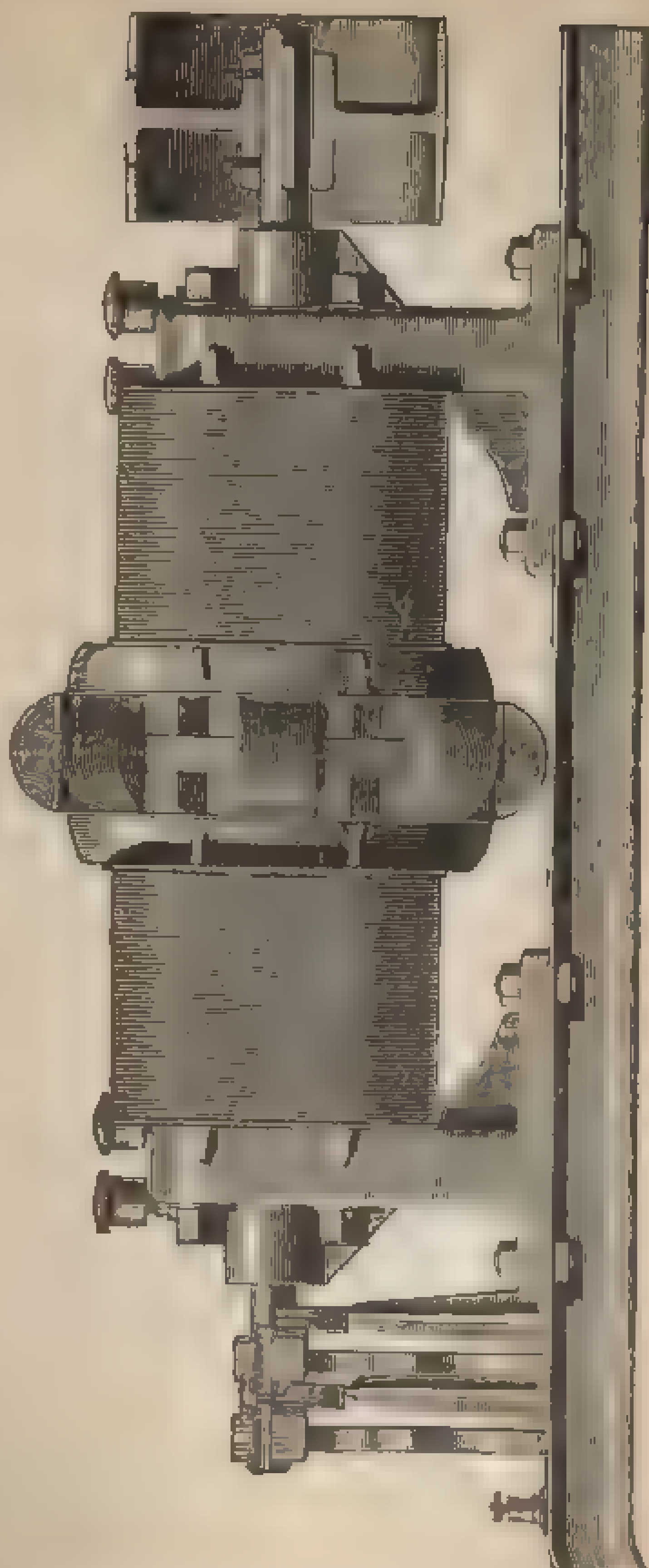
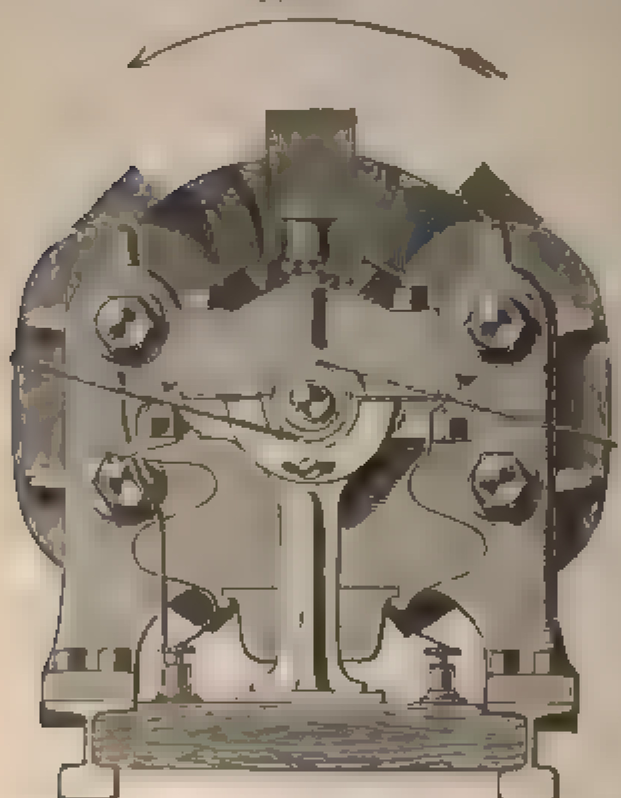


Fig. 211

different layers being separated as in the case of the armature by cotton-cloth. These coils are joined up in series, and as the current generated by the machine fluctuates more or less, there is a tendency for eddy currents to be induced in their unlaminated cores. This is overcome by the simple device of interposing between the coils and the iron a thin tube of copper, in which the currents are induced instead of in the iron. These induced currents tend to reduce the fluctuations of the primary current.

FIG. 212.



The pole pieces are extended so as to embrace an unusually large part of the armature, and the opposite pole pieces are similarly magnetised. The lines of force are not projected axially through the armature, but entering the core on both sides, by the projections formed by the H pieces, tend to pass circumferentially round a portion of it and leave it at another set of H pieces, near the other pole, the lines of force being in this way urged through and cut by the coils as they rotate.

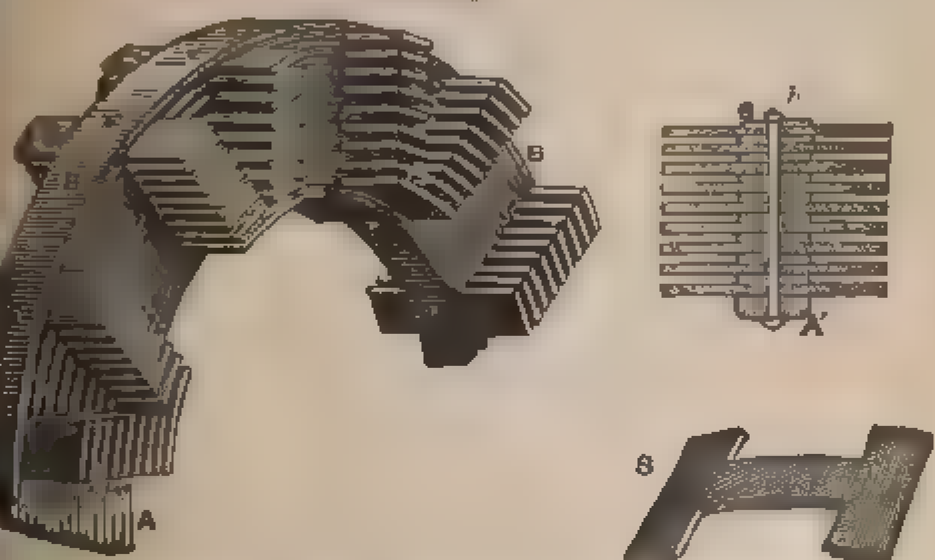
The diameter of greatest activity is approximately in a line with the upper horn of the right-hand pole-piece, and the lower horn of the left hand pole-piece (fig. 212), as will be gathered from the position of the brushes, the direction of rotation being left-handed as viewed from the commutator end. As the machine is designed to give a nearly constant current, the reaction of the armature on the field, and therefore also the lead of the brushes, varies very slightly under ordinary changes in the load.

The machine illustrated is designed to supply 55 arc lamps in series, with a current of 10 amperes. The figures are b

to scale, the principal dimensions being: length of bed-
ft. 10 in., width 2 ft. 5 in., height of highest point 3 ft. $1\frac{1}{2}$ in.,
diameter of armature 2 ft. 9 in. The diameter of the shaft
., its centre being 1 ft. $9\frac{1}{4}$ in. above the ground line. The
measures 18 in. by $12\frac{1}{2}$ in.

brush-holders are connected to terminals on the bed-plate
ns of flexible copper strips, the method for adjusting the
being shown in fig. 212. Each pair is carried by a lever

FIG. 213.

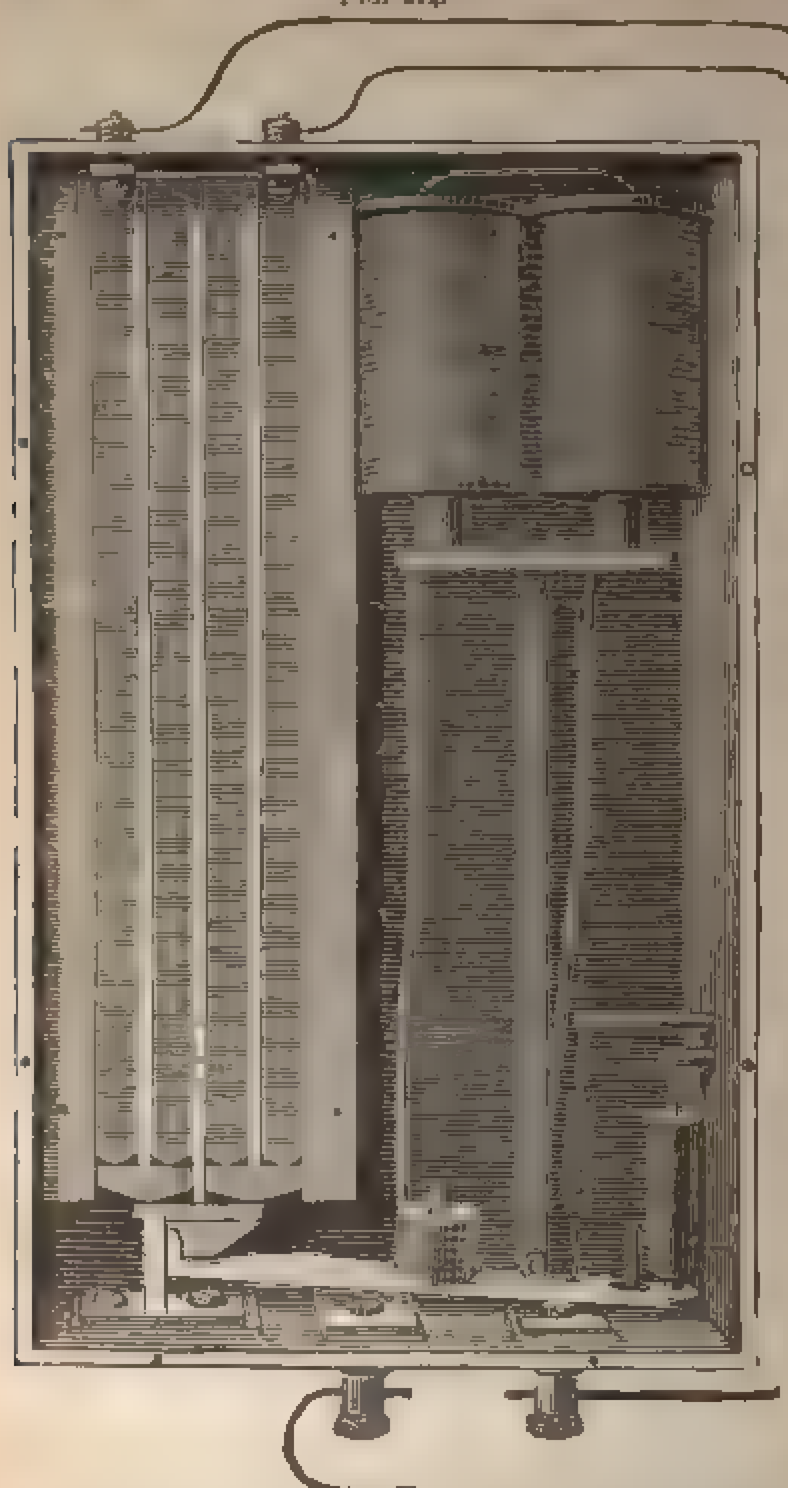


can be turned round the shaft, its range being, however,
by the length of the slot in the semicircular collar directly
the shaft. One end of the lever is furnished with a small
ion riding over a curved guiding-fork, the position on the
ing fixed by means of a set screw.

ough this machine is capable of driving as many as 55 arc-
ed in series as its maximum load, the number of lamps
ded in circuit may vary considerably from time to
of switching out a lamp reduces the external resist-
chine being series [illegible]d, the current strength is
ssed. It is ne[illegible]ss essential that under all
current st[illegible] 10 amperes should be
[illegible] necessary. The
[illegible]sh is ingenious, and
[illegible] al columns of thin
[illegible]e partitions. These

columns are joined in series between the two terminal se
the top, connection being made between the two inner colu

FIG. 214.



the top, a
tween the
pairs of c
at the botto
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slabs. Wi
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top termin
the ends
field magne
across which
carbon c
form a
whose res
can be vari
altering the
sure upon
plates. Thi
sure is aut
cally inc
when the c
rises abov
normal valu
the resistan
the shunt
thus reduc
larger prop
of the curre
abstracted
the field-ma
and the st
of the field
current ke
their proper
The method of accomplishing this is illustrated in the figure
The two solenoids are joined up in the main circuit by

is shown at the bottom. Projecting partly into the soft iron cores, permanently fixed to a common yoke-ntre of which carries a brass rod attached at its lower one end of a lever, whose fulcrum is a knife-edge at eft end. When by the switching out of lamps, or from use, the main current passing through the solenoids e cores are sucked upwards with greater force, and the ch the four columns rest is raised through a short dis-lever, thus compressing the carbon plates and reducing sistance, with the result that the current in the field-roportionally reduced A dash-pot is attached to the the lever to prevent sudden or jerky movements, the tment being obtained by means of a spiral spring and weights slipped over a vertical pin.

namos are made in a great variety of sizes and forms, or various classes of work, the armature being some-d with twelve coils, in which three sets of commu-brushes are required. A very remarkable machine tructed for the purpose of smelting aluminium, the ired being 3,200 amperes with an electro-motive force . Its actual speed when developing its maximum little over 400 revolutions per minute. The cores of gnets are of cast-iron and cylindrical in shape, with a 11 inches and a length of 16 inches, the total weight er with which they are wound amounting to 542 lbs. re contains 825 lbs. of copper wire, and has an iron ng 1,600 lbs. The machine measures about 15 feet eet wide, and stands 5 feet high.

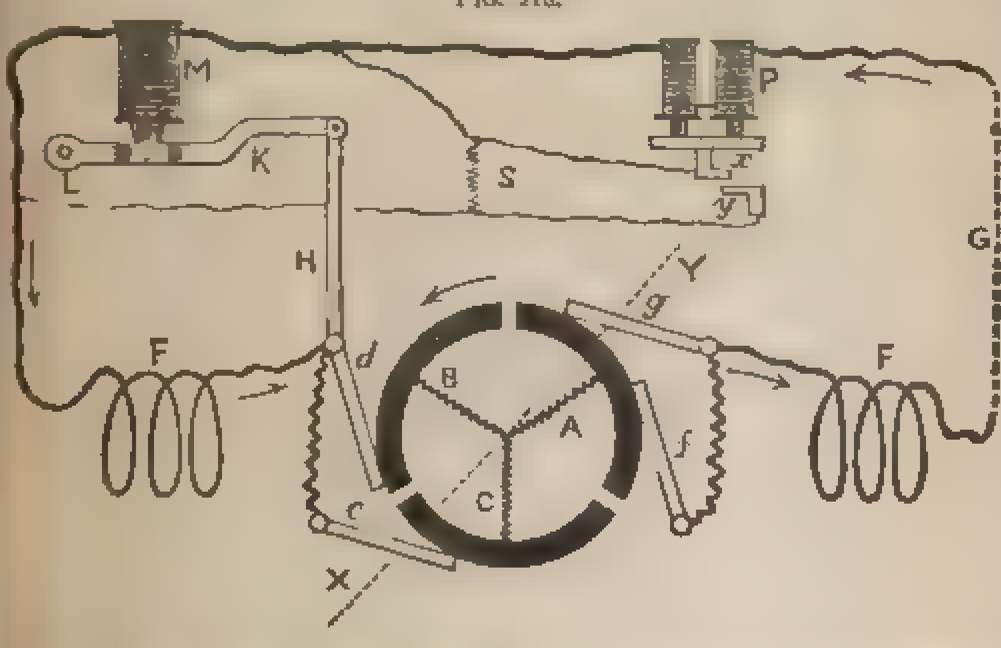
other form of open-coil dynamo in general use is the uston, of which a general view is shown in fig. 215. by itself, having many peculiar features, altogether hose of any other with which we have dealt. eld-magnets placed horizontally, with their oppo-h other The comparatively little iron in ich consists -iron tube flanged at both the arma with a spherical cavity to he sh mature itself is that of a omew range, and it revolves

other 120°, and the *whole* of the
half of the second coil is then
finally, the remainder of the fi
sponding first portion.

When the armature is rotated
are induced in each of the coi
place in each case when the pla
the lines in the resultant field.
course, distorts the field somew
certain angle in the direction of
line X Y in the lower part of fig

ont of the other. The consequence of this arrangement is that he most active coil is joined up in series with the remaining two ss active coils, which are joined together in parallel. In the se shown in fig. 218, the coil A is approaching the best position; hile B and C are in the intermediate stage, and are therefore ined up in parallel. The resulting E.M.F. is, consequently, that ue to the mean E.M.F. of B and C, added to the separate E.M.F. f A. As the armature rotates, B approaches the best position, and s commutator segment alone is then in contact with the brushes , *e*, while C and A, which are brought to the intermediate positions, re joined in parallel. These changes are continually repeated as he coils pass through the different portions of the field.

FIG. 218.



As in the case of the Brush dynamo, this machine being series ound and used on a circuit of high resistance for driving a large umber of arc lamps joined in series, the switching out of any f the lamps tends to cause an increase in the current strength, hile, conversely, the switching in of lamps causes a diminution. Hence, in order to keep the current at a nearly constant strength, ome regulating device is necessary. The method adopted consists in simply altering the position on the commutator of the two rushes forming each pair. It will be observed, from the commutator in fig. 218, that, the brushes being 60° apart, no coil is thrown out of circuit at any part of the revolution, and this is what

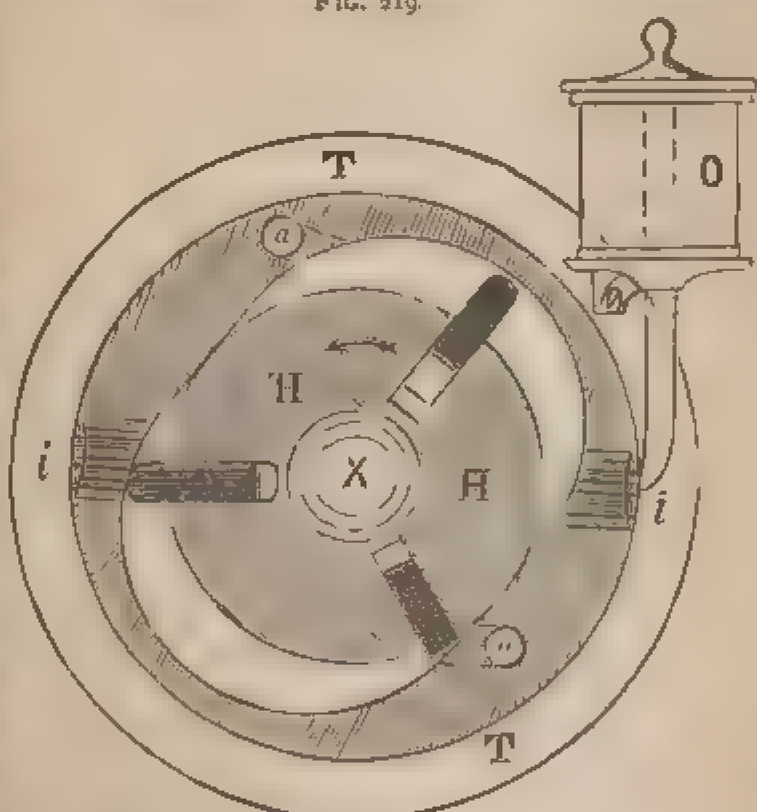
we may call the normal state of affairs. When, however, the current falls in strength, each pair of brushes is closed up automatically, so that all the coils are, in turn, disconnected the moment when they are passing the neutral position, and are therefore nearly idle. The E.M.F. of the two coils in parallel is the mean of their individual E.M.F.s, and is, obviously, weakened by a comparatively idle coil, so that, at the moment when the idle coil is thrown out, the E.M.F. resulting from the other of the two coils in question is greater than it would be were they both in parallel. If this closing up of the brushes were to take place, then, when the armature is in the position shown in the figure, the comparatively inactive coil B would be disconnected, and A and C joined to the external circuit in series. The maximum E.M.F. would be developed when each pair of brushes is so closed as to form practically one brush, in which case the least active coil would be always out of circuit and the other two joined up in series. From this point any opening of the brushes puts two of the coils in parallel for a greater or less interval of time, and reduces the E.M.F. actually developed; therefore when the current becomes abnormally strong, the brushes are opened until the E.M.F., and, consequently also, the current, are reduced to the normal value. The motion given to the brush holders by the regulator is such that the following brush of each pair travels three times as fast as the leading brush.

The brushes *d*, *e*, *f*, *g*, are mounted on a double lever, having a scissors like movement about a common centre. The end of the lever carrying the brushes *d* and *f* is connected by the bar H to the armature K, under the electro magnet M. This armature is hinged at L, and when the current in the main circuit becomes excessive, K is attracted, *d* and *f* are drawn back over the commutator, while *e* and *g* are pushed forward by a simple combination of levers not shown in the figure. The electro magnet M and the double solenoid P are both in the main circuit with the field magnets F F and the lamps, and normally M is short-circuited by wires whose circuit may be broken at *x y*. The contact *x* is attached to the yoke of the two cores of the solenoids, and the first effect of an increase in the current is to raise the cores, break the contact at *x y*, and so cause the whole

urrent to pass through M, which then attracts K and opens hes. A high resistance carbon shunt is inserted at S to the spark at *x y*. It will be noticed that the end of the M is shaped somewhat peculiarly and fits into a corre- g cavity in the armature; this shape is calculated to dimi- force of attraction uniformly as the armature recedes core. The regulating apparatus is shown in position in The small cylinder to the right of the electro magnet h-pot for steadying the movements of the lever.

re is one other device pertaining to the Thomson Houston h a reference is necessary, and which is employed to s the exces king caused ing out the when fairly and which otherwise destroy the ator. The ts are sepa- by air spaces, in front of ading brush ed a nozzle delivers a blast of air at moment that brush breaks t, and so ac- blows out the

FIG. 219.



The automatic 'blower' by which these timely puffs are ed is shown in section in fig. 219. A circular steel hub, eyed on to the shaft, X, and revolves left handedly in an chamber in the fixed [illegible] x T T. Air enters this chamber rtures at [illegible] are protected by wire gauze hub H [illegible] th three radial slots, in and etal [illegible] ps can slide freely. As sl [illegible] by centrifugal force, and,

pressing continually against the walls of the chamber, forc[...] in front of them and out at the holes *a a*, to each of which [...]nected one of the two nozzles above referred to. The c[...] is fixed to the framework of the machine in the necessary [...] for the maximum force of the blast to take place at th[...] moment. *o* is a vessel from which oil passes into the [...] chamber through the aperture *i*.

The machine illustrated is designed to supply a cur[...] about 9½ amperes to 34 arc lamps in series. The arm[...] 2 feet in diameter, over all, and the resistance of the field-m[...] and of the armature is in each case 10½ ohms.

In addition to the dynamos which have been described [...] and the preceding chapters, there are many others to wh[...] scope of this work has not permitted us to refer, although [...] them are well worthy of study. We believe, however, th[...] enough has been said to give the student a good insight i[...] science of dynamo building as it is now practised. W[...] have given sectional views or working drawings, they have [...] most part been specially prepared for this work and [...] machines manufactured since the summer of 1889.

A comparison of these chapters with works of a similar [...]ter published a few years ago, will show that the modern [...] in dynamo design is towards simplification and unifor[...] detail. As an example of the latter, we may cite the cons[...] of commutators, in which the materials now employed are [...] always exactly alike, while in the manner of building up th[...] so as to prevent the sections flying out, there is very li[...] difference to be found. This similarity is what might, perh[...] anticipated, for if the vast number of experiments which [...] been performed by the various manufacturers to determine [...] is the best appliance to perform a given kind of work, hav[...] equally exhaustive and accurate, an almost identical result [...] have been arrived at. Thus, no metal has been found supe[...] hard-drawn copper for the bars of a commutator, while [...] extremely difficult task of satisfactorily insulating these bars [...] case of a closed coil commutator, nothing has been disc[...] which approaches mica; indeed, were this mineral not ava[...] it is probable that some alteration would have had to be [...] in the general design.

[Gr]eat things were at one time expected of asbestos for [insula]ting purposes, but it proved to be a good absorbent of oil [and w]as charred by the sparking, while the adhesion of metallic [partic]les abraded from the bars and brushes soon developed a [great]er or less amount of short-circuiting with its concomitant [evils]. A somewhat similar result attended the use of simple air-[space]s for insulating the bars, for the metallic dust or scrapings [accum]ulated sooner or later at the bottom of the spaces, which, [bein]g numerous, were necessarily narrow. Occasionally a special [form] is given to a commutator; for instance, that of the small [dynamo] shown in fig. 134 is built against the end of the armature, [the i]ndividual bars being disposed radially. The object here is to [reduc]e the length of the machine. A special commutator is also [emp]loyed with the machine illustrated in fig. 221, the object of [whic]h is explained in the description.

[A]gain, the lamination of the core of an ordinary cylinder or of [a rin]g armature is a matter upon which little doubt now exists, for [it is] as certain as it well can be that the magnetic resistance should [be k]ept as low as practicable, a result only to be arrived at by [secu]ring metallic continuity in the direction of the lines of force [and u]sing extremely thin insulation; while, on the other hand, the [lamin]ation must be carried far enough to sufficiently reduce the [eddy] currents. Nothing better, therefore, can be devised than a [core] of thin iron plates of high permeability, separated by the [thinnes]t possible layer of insulating material, the only doubtful [point be]ing the thickness of the plates. Such experiments as [those re]ferred to at the end of the preceding chapter may help to [settle th]is point, and it is just possible that by this means some [informat]ion [illegible] eventually be gained which will enable the [illegible] to be minimised.

[illegible] [clo]sed-coil armatures it is probable that the [illegible] in the future [illegible] even less frequently [illegible] the drum ty[pe illegible] a simple field, and [illegible]r field, h[illegible] proved to possess [illegible]. Th[illegible] we see that the [illegible] the [illegible] types to one or [illegible] almost every in-[illegible] [pec]uliar to itself. [illegible] [illegible]nt in the con-

struction of dynamos is in the form and arrangement of the field-magnets, and these matters are frequently determined by local circumstances. For example, one maker may have tools capable of doing a class of work altogether out of the question at another factory. Or, again, the question of weight may have to be taken into account, dictating the use of wrought-iron where otherwise cast iron would be the more economical.

The theoretical form of field magnet, circular in section (so as to require the minimum amount of wire), and made of soft iron without molecular discontinuity, is too expensive and inconvenient to be rigidly followed, especially in large machines. Equally powerful fields can be produced with rather more copper wire and a little greater expenditure of power in the field magnet coils by the use, partially or entirely, of cast iron, with close fitting joints.

The great variety in the form of field-magnets is also largely due to the difference in the views of the various makers as to the method of obtaining the most economical construction. Very few now manufacture dynamos with the armature at the lower extremities of a pair of vertical field magnets, where slabs of zinc or frames of gun metal have to be interposed between the pole pieces and the iron bed plate, to reduce the magnetic leakage. Sometimes this type is adopted in order to economise space and make the machine as squat or short as possible, three coils being then wound on the field magnet, one on each leg and the third on what we are accustomed to call the yoke.

The purpose for which dynamos are most frequently designed is to light a number of incandescent lamps joined up in parallel circuit. It is necessary to maintain a constant potential difference at the terminals of these lamps, say of 110 volts, and consequently the machine employed should be shunt wound, with a very low resistance in the armature; or, if the number of lamps is likely to be subject to considerable variation, the machine must be compound wound. For the important work of charging secondary batteries, a simple shunt-wound machine is the most suitable. A series dynamo is, of course, capable of performing this work, but it requires to be used with extreme care, because as the electro-motive force of the cells rises, its opposition to that of the machine becomes more pronounced and the current falls

alue. The polarity of the field-magnets may, indeed, be tually reversed, when the current from the cells will drive the hine as a motor. On the other hand, when using the shunt-hine the electro-motive force of the cells tends to increase the ent passing through the field coils, whence the danger of rsal is diminished.

Many dynamos are now employed for the deposition of metals, roplating, &c., and for this purpose they are required to ish very heavy currents at a low potential difference. They frequently series-wound and it is necessary that the internal tance should be extremely low, otherwise considerable power ld be wasted by the passage of the currents, which sometimes ed 1,000 amperes. To obtain this low resistance a drum ture may be constructed with very massive bars for the active ductors, the field-magnet coils consisting of a few convolu s of massive copper band. An electro-motive force of from o eight volts is usually ample, and this, notwithstanding that e are but comparatively few active conductors round the ture, can be obtained without the necessity for driving at a speed. But it is not an easy matter to secure these massive , and consequently many machines are made with a number irly thick wires joined up in parallel to form one conductor. rder to reduce as far as possible the loss of energy at the mutator it is essential that the brushes should be large, and mount of contact surface considerable. A large machine, what similar in appearance to that depicted in fig. 185, has constructed for electro-deposition work; it develops the ratively high E.M.F. of 50 volts, and can yield 1,000 amperes eed of 350 revolutions.

polar machines, as has already been indicated, afford a r easily securing mechanical strength with extremely low e.

upplying current to a number of pieces of apparatus n series, whether arc-lamps, low-resistance incandescent notors, it is necessary to maintain a constant current nditions. The two open coil machines described in r, and the dynamo illustrated in fig 194, are suitable s of work.

CHAPTER XII.

MOTORS AND THEIR APPLICATIONS.

WE must now give some attention to the important cla dynamo electric machines employed for the purpose of conver at any desired point, energy supplied to the machine in the of electricity, into energy in the form of mechanical motion.

In its widest sense this conversion rests upon the fact whenever any of the lines of force forming part of two separ generated magnetic fields traverse a common space, there decided action between the two sets of lines, the tendency to so alter their paths that as many lines as possible shall coi in direction. By bearing in mind this simple general rule, difficulty should be experienced in predicting the results will follow, even in complicated cases. This mutual action place independently of the means by which the fields are veloped, whether by currents in two wires (straight or coiled, or without cores), or by permanent magnets; or, the one fie a current in a wire and the other by a magnet. In the effo make the coincidence a maximum, both fields are distorted the configuration which they would independently have re and this configuration is again assumed immediately they removed from each other's influence. Consequently, whe lines of force pertaining to two fields approach each other, mutual action sets up a stress, the effect of which is a tende impart such a motion to the material substances (whether a bar or a conducting wire), employed in generating the fields, make them take up positions in which the lines of for both fields coincide to the greatest possible extent. The str the fields, the greater is the force thus acting, and, if suffic strong, mechanical motion is imparted to that body which m

y. For instance, suppose one field to be a simple
l between the two pole-pieces of a powerful field-
as has been described, and the other field to be
a current in a circular loop of wire. If the loop is
lly with its edges towards the pole-pieces, that is,
f parallel to the lines of force of the field-magnet,
of its own field will be projected at right angles to
her, and the field-magnets being too massive to move,
if freely suspended, immediately turn round through
lines of force of the other field thread through it in
ction as its own lines. If free to move in any direc-
ate position of rest will be in the densest portion of
e the number of lines passing through it, and coin-
ection with its own lines, is a maximum. If the
gh the loop is then reversed in direction, it will turn
und until the lines of both fields again coincide.
hus a means of imparting mechanical motion to a
ance, in this case a loop of wire; and a continual
n can be maintained by reversing the current in the
at moment, viz. just when its momentum has carried
nd the point which, in the absence of this reversal,
position of rest. It remains to be seen how the
tically applied, on a scale such that the force with
ble body is urged into a new position may amount
power.

he simple case of a closed-coil armature with a
tor, as illustrated in fig. 149, it will be observed
sent through the two coils in parallel, while in
n, no movement results when the direction of
that the lines of force due to it coincide in
of the fixed field. This is the position of
and if the cur[illegible] it is reversed, it will
lution until [illegible] coincidence again
t can be s[illegible] brushes pressing on
[illegible] and so p[illegible] each segment slides
[illegible] brush [illegible] position of rest is
[illegible] the cur[illegible] reversed, and a
[illegible] With [illegible] oils, the armature

might come to rest suddenly at a dead point, and would not start again from such a position, but the number of coils can be increased with advantage until we have, practically, an armature similar to those used in generators. On a current being sent through such an armature, each coil strives to set itself with its plane at right angles to the field, in which position the coincidence of the two sets of lines is at a maximum. Immediately the coil arrives at this point, the current in it is reversed, causing it to exert a similar force in the same circular direction, during another half revolution.

The armature may be of the ring, drum, or flat disc type, and it fortunately happens that most of the principles underlying the design and construction of a good generating dynamo, hold equally well for a motor. The fixed field is usually supplied by powerful electro-magnets as in the case of generators, these being excited by a current from the same source as that which supplies the armature. Many of the troubles which in dynamos are avoided or reduced by the employment of a fixed field sufficiently strong to overpower that developed by the armature, are also inherent in a motor, and may be avoided by the same arrangement. In a motor the question of weight is frequently of considerable importance. For instance, the machine may be employed for the purpose of propelling a vehicle, and in such cases the weight of the motor is added to that of the vehicle, and involves a proportionally increased expenditure of power in moving it. Again, in constructing a motor, even more care must be exercised than with a dynamo, in rendering the armature able to resist sudden heavy stresses without risk of damage, the reason for which will be more apparent presently.

We have already learned that when a conductor moves through a magnetic field in such a manner that it cuts the lines of force transversely, an E.M.F. is induced in the wire, this E.M.F. depending upon the density of the field and the velocity of the wire, the cause which sets the wire in motion being quite immaterial. And if an independent current is already flowing in the wire, the electro-motive force induced by the motion, will either tend to increase or decrease this current, according to its direction. Now when a wire, free to move, is placed in a certain position in a

etic field, and a current is sent through it, it quickly moves new position. But in the very act of moving across the the wire cuts the lines of force, and an electro-motive force sequently induced in it. As such reactions always tend to he motion of the moving body, and as any reduction in the nt must necessarily reduce the force with which the wire is d (by the mutual action between the fields), the induced must oppose and reduce the current which is flowing.

consequence of this 'counter electromotive force,' the current a given external source of E.M.F. can send through a motor, with the speed at which the wire of the movable part of the ne is at the moment cutting the lines of force of the field. the revolving part is forcibly restrained from moving, the nt is at its maximum, being simply the quotient of the E.M.F. ed by the resistance But when it is allowed to move, the nt immediately falls in value, and the higher the speed, the r is the strength of the current. This may be observed mentally by placing an ammeter in circuit with a battery motor, and then varying the speed of the latter.

ow, any one of the dynamos hitherto described can be used motor. For instance, we may take a direct current series-d machine, and, by simply passing a current through it from tery of secondary cells, can cause the armature to rotate ly. The force with which the armature moves, depends upon rength of the fields produced by it and by the field-magnet, hese in their turn depend upon the strength of the current.

he internal resistance of a secondary battery is very low, and t of the machine is also low, an enormous current will pass the armature is at rest; sufficiently strong, if maintained ny length of time, to damage it. But immediately the ture begins to move, this enormous current falls, until pre- the speed of rotation and the counter electromotive force become so high that only a very small current can flow, the with which the armature turns, or the torque,[1] being, of e, also considerably reduced. This variation is extremely

[1] The 'torque' is the moment of the force which tends to cause rotation. In e it is equal to the length of the arm, that is, the radius of the armature, ied by the pull at the circumference on the conductor.

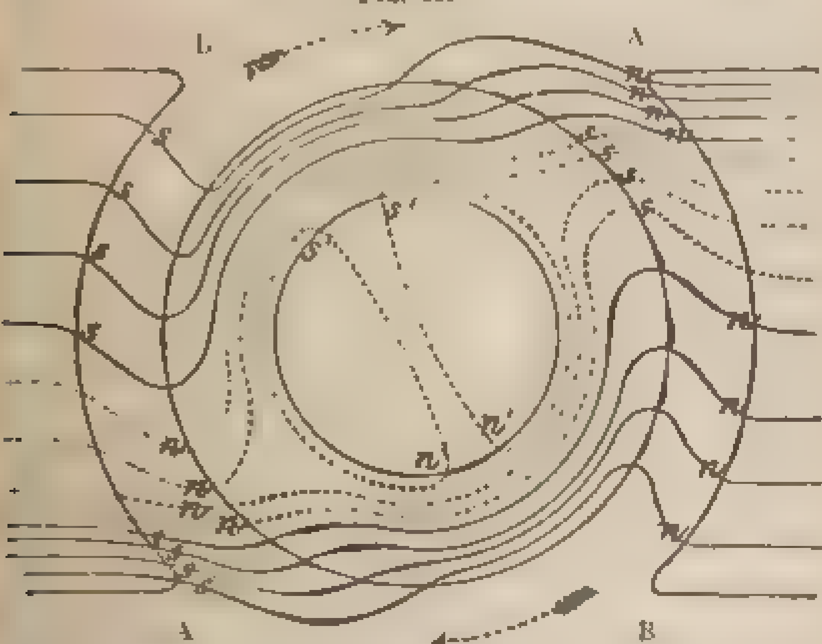
effected, and before any d
over-heating. The necess
sudden heavy stresses as th
heavy load, requires exce
mechanical construction of
is here directed to the mach
armature conductor lies in
plate of which bears directly
tion being such as to rende
enormous torque without inj

Supposing the field to
current in the armature of
must be the reverse to its
if the direction of rotation
case ; indeed, we have just s
is opposite to that which pr
fore, if the direction of the
which would be developed b
of the armature or of the fiel
be reversed ; or if a rotatio
the connections should be lef
round to suit the reversed
other hand, will, without any
if an E.M.F. opposite to tha

he distortion of the field observed when a machine is used generator also occurs when it is employed as a motor, because, the brushes are at zero, the lines of force of the armature are at right angles to those of the field-magnets. But the ion of the current, and therefore of the lines of force, being ed in the case of a motor armature, the direction of the ant field is also different. The amount of the distortion ds, obviously, upon the relative strengths of the two fields. very slight when the field-magnets overpower the armature, all cases the direction of the resultant field is such that the es must be shifted *backward* to place them on a diameter ht angles to the lines of force, and so to avoid sparking.

he distortion of the field of a motor is illustrated in fig. 220, should be compared with the corresponding figure (156) for

FIG. 220



erator. The density of the lines of force is greater at the A A which the armature is approaching, and, as a conse- ce, any irregular distribution of iron in the armature core s stronger eddy currents and develops more heat at these , than at the horns B B from which the armature is receding, the case of a dynamo. With an ordinary armature, however, eating is not very great, and in all cases it is influenced to a extent by the fact that a current of cold air is drawn in at

A A and ejected somewhat warmer at B B. In the case of a motor, therefore, this air current tends to reduce, and in the case of a generator to increase, the difference of temperature between the two horns of each pole piece.

The current through the armature of a motor frequently varies considerably, and this may cause a shifting of the resultant field, and therefore also necessitate an alteration in the position of the brushes, but in all cases a reduction in the angle of lead and immunity from sparking with a variation of the armature current may be obtained by employing a very powerful field relatively to that produced by the armature. But this necessitates considerable weight, especially in the field magnet cores. Hence, the superiority of wrought-iron of high permeability is apparent, although even when this is used the weight of a motor built upon this principle is still considerable. As we shall see presently, the most effective plan of constructing a light but efficient machine is to arrange that the armature field shall be very powerful and reinforce that of the field magnets, special precautions being taken to prevent the sparking which would otherwise ensue. But at the same time it must be remembered that the advantages accruing to the use of powerful field magnets, even at the expense of extra weight, are not lightly to be thrown away, and that in ordinary cases it is rarely true economy to sacrifice much in order to save a little weight.

The electrical power may be supplied either at a constant pressure, or constant current; in the former case regulation is comparatively easy, while in the latter greater economy in the distribution of power can sometimes be effected. Supposing a constant potential to be maintained at the terminals of a shunt-wound motor; the current through the field magnet coils will always be the same, and therefore the strength of the field remains constant, but the current through the armature depends upon the speed of rotation, being, in fact, determined by the excess of the applied electro-motive force over the counter electro-motive force. Supposing the machine to be employed in driving a tram car then, for example, when the car commences to mount an incline, the armature shaft is called upon to perform additional work, which tends to reduce the speed of rotation; this, however, by reducing the counter-electro-motive force, immediately allows a stronger

current to pass through the armature, and affords the necessary electrical power to perform the extra work. On the other hand, should the car be allowed to attain a high speed in descending an incline, the counter-E.M.F. would reach a high value, so high in fact that very little current would pass through the armature, whence very little electrical power would be expended. The demand upon the source of the electrical power is thus to a certain extent automatically regulated in a very simple manner according to the requirements, and this effect of the counter electro motive force obtains, whatever the purpose may be for which the machine is employed.

If the armature resistance is extremely low and that of the shunt-coils high, and if the field-magnet develops a much greater field than the armature, the variation of lead will be but slight, and further, the machine will to a great extent be self regulating as regards speed. But since these conditions are not always obtained in a motor to the same extent as in a dynamo, chiefly on account of the anxiety to reduce the weight, few shunt motors are sufficiently self regulating to meet all requirements We have seen that when an additional load is thrown on the motor, the resulting reduction in speed immediately allows the passage of a stronger current through the armature; but if the speed is to be kept constant, the counter electro-motive force also will be constant, and then the current through the armature can hardly vary at all, so that the two conditions are opposed to each other. But by reducing the strength of the field developed by the field-magnets, the counter E.M.F. can also be reduced, and therefore a stronger current can be passed through the armature when rotating at a given speed. It is necessary, then, to devise some means of reducing the strength of the field when the load is increased and the current in the armature rises. The simplest way of accomplishing this is to place a few turns of thick wire round the limbs of the field magnet, in series with the armature, but wound in such a manner as to magnetically oppose the shunt-coils instead of assisting them, as in the case of a compound-wound generator. The effect of these series-turns in weakening the field becomes greatest when the armature current is strongest, and *vice versâ*; but it should be observed that since the strongest

current which can pass through the armature does so when it is at rest, the armature may start in either direction as determined by the shunt-coil field, or the field produced by the heavy current in the series-windings. To avoid any uncertainty, it is usual to lead the ends of the two windings and of the armature separately to the switch board, and to reverse the current through the series windings, so that both shunt- and series coils act together in developing a strong field at the moment of starting, the series turns being joined up in the normal manner when the speed rises above a certain value.

The field of a shunt motor may also be weakened by inserting resistance-coils as required, either by hand or automatically, or by altering the ampere-turns in any other manner. It appears at first sight somewhat paradoxical that the speed of a motor can be increased by reducing the strength of the field, but the reduction of the counter electro motive force of the armature, as mentioned above, satisfactorily explains the matter. The case for a series motor fed with a constant current is different, and the distinction must be clearly borne in mind. If the load is decreased, the speed increases, and so gives rise to a higher counter E.M.F., but the generator responds to this and maintains the current constant. Consequently the speed of the machine increases enormously when the load is lightened to a great extent, and it is then that unless care is taken considerable damage may be done. The weakening of the field of a series motor reduces the power given out, and therefore, also, reduces the speed if the load and the current through the armature are unaltered. The alteration in the strength of the field is conveniently effected by shunting the field-magnet with a variable resistance, and the application of one such method will be considered presently. We shall also refer to the manner in which highly successful results have been achieved by means of series motors supplied at a constant potential.

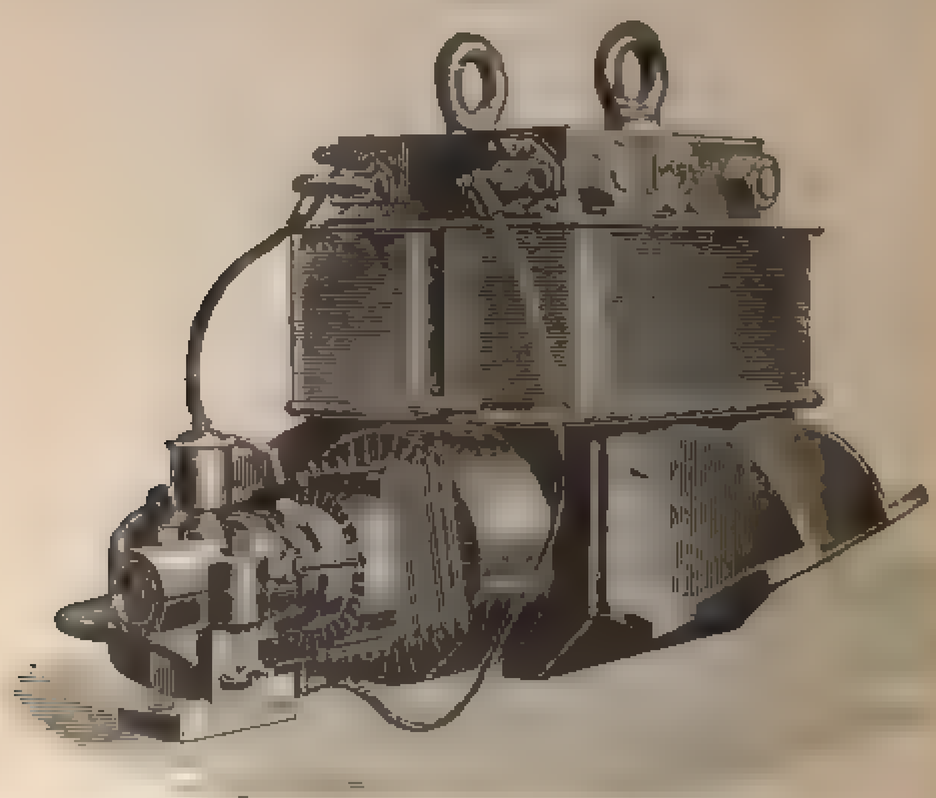
Only a portion of the power given electrically to a motor is converted usefully into mechanical power, a part being spent in heating the armature, field-magnet coils, &c. When the armature is at rest the whole of the electrical power absorbed by the motor is so converted into heat, and the efficiency of the machine, that is, the ratio of the useful power obtained on the shaft to the total

ower supplied, is at its lowest value, viz. nought. When the mature is moved, the useful performance of work begins, and as e current also falls in strength, the power wasted in heating ecreases. The higher the speed of rotation, the higher becomes e counter-E.M.F., and the less becomes the power wasted as heat the conductors; in fact, the ratio of the power usefully ab-rbed by the motor to the whole power supplied, is very nearly oportional to the ratio of the counter E.M.F., to the E.M.F. plied at the terminals of the machine. The efficiency of the chine is therefore highest when the load is a minimum, that is, hen it is doing least work per revolution, while the torque, or e force with which the armature tends to rotate, is greatest when e load is sufficiently great to prevent the armature turning, and hen, therefore, it is doing no external work at all. Now when a otor is running at a high speed it performs very little work deed during one revolution, although, the number of revolutions ing great, a considerable amount of work may be performed ring a given interval of time, say one minute. On the other nd, when the speed is very low, the amount of work per revolu-on is comparatively great, but the small number of revolutions per nute prevents the quantity of work reaching during that interval a ry high value. By considering these two extreme cases, it might supposed that there is a certain intermediate speed of rotation which the work performed by any given motor is a maximum. his is the case, and the speed of a motor at which it can perform e maximum amount of work per minute is that speed at which the unter-electro-motive force becomes equal to the electro-motive rce applied at the terminals. This result is quite independent the *efficiency* of the conversion, which, as we have seen, in-ases with the speed of rotation.

In fig. 221 is illustrated a motor which was constructed by ssrs. Goolden for an electric launch. The field magnet is of single horse shoe shape, the cores being of wrought iron, secured a wrought-iron yoke-piece by two horizontal bolts. On the er side of each pole-piece is a gun-metal supporting bracket h two flanges, shaped to fit the ribs of the boat. One bracket at the back in the figure) is extended on either side to form bearings for the armature shaft.

The machine is shunt wound, the field magnet coils consisting of 2,680 convolutions of No. 14 S.W.G., having a resistance of 6·96 ohms. The armature is of the drum type, and is wound with two No. 14 S.W.G. wires in parallel, there being 216 convolutions of this double wire, giving a resistance from brush to brush of 0·2 ohm. Each section has six turns, so that there are thirty six bars in the commutator, which is insulated throughout with mica. The adjacent end of the armature is covered by radial extensions of the commutator bars, the mica insulation being also extended

FIG. 221.



to the periphery. The other end of the armature is covered by a metal plate of an equal diameter, the rest of the armature being enveloped by a waterproof material securely banded on, so that the whole is rendered completely watertight. The armature shaft is, at the end remote from the commutator, coupled direct on to the shaft of the propeller. The armature brushes and field-magnet coils are connected to separate terminals leading to the controlling switch, and the motor is reversed by simply reversing the direction of the current through the armature. To render this practicable, the brushes are of a special type (see fig. 227).

[co]isting of steel springs placed flat against the commutator, and [prov]ided with solid carbon blocks for making contact, the requisite [press]ure being given by india-rubber bands passing round hooks [at t]he ends of the springs. This motor develops five horse-power [whe]n running at 500 revolutions per minute; the current is [sup]plied by secondary cells, the machine being designed to carry [...] amperes at 95 volts, but the margin is such that it can safely [carr]y up to 70 amperes for several hours without risk of damage [by o]ver-heating.

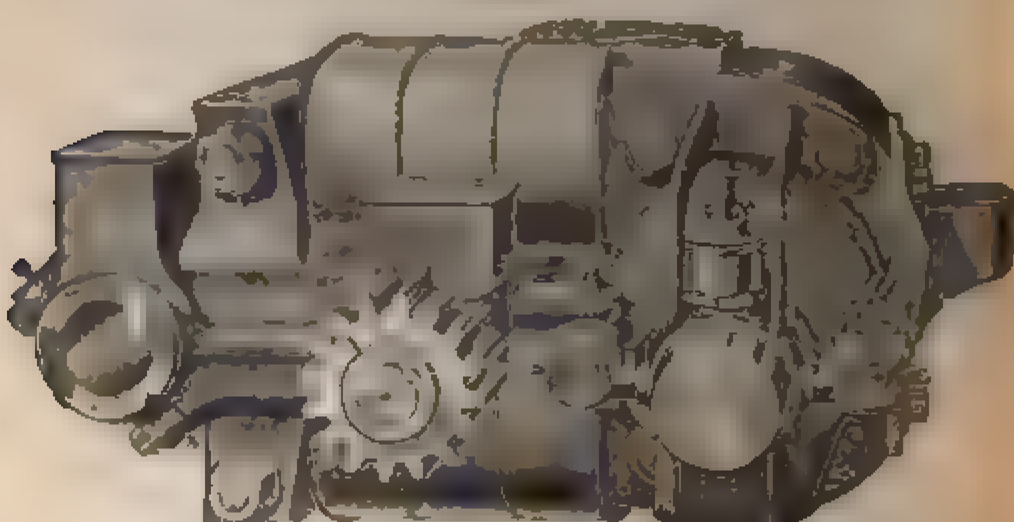
The efficiency of this motor is about 85 per cent., which is [high] for so comparatively low a speed as 500 revolutions per [min]ute. In most cases the difficulty of obtaining a machine of [reas]onable efficiency at a low speed, without abnormal pro[port]ions and correspondingly heavy weight, renders it necessary [to r]un at a high speed, and to effect the reduction required, by [suit]able gearing. Thus, for example, the wheel of an ordinary [tram]-car travelling at seven miles per hour does not revolve at so [high] a speed as eighty revolutions per minute, and it would be [impo]ssible to construct a practical motor to run at this low rate. A [mac]hine running at 720 revolutions might be employed, by intro[duci]ng gearing which would reduce this speed to about one tenth. [The] selection of suitable gearing is not, however, an easy matter, [for it] must be light, strong, and durable, and should produce [neith]er noise nor vibration in working; and, while absorbing little [power] in friction, it must be capable of withstanding dust and [dirt, o]r of being easily protected. Some very good devices, depend[ing o]n friction to transmit the power from a small wheel on the [rapidly r]otating armature shaft to a larger pulley on the axle, have [been em]ployed with fair success on lines where the gradients are [light, b]ut where the power required to be transmitted is at times [heav]y, this method is not to be relied on. By means of a pinion [and spu]r wheel, with or without an intermediate counter-shaft, [the] power can be transmitted. One principal objection to [this gearin]g is that it is noisy; the teeth of the pinion on the [armature s]haft also rapidly show signs of wear.

[The ne]cessary reduction in speed can also be obtained, and in [a satis]factory manner, by means of a screw and worm-wheel; [the] screw, driven by the motor shaft, gearing into the

teeth of a worm-wheel on the axle of the car or on a counter-shaft. Chain gearing is also employed; in this case an endless chain passes over a small toothed wheel on the motor shaft and a larger one on the axle, the teeth of the wheels fitting into the links of the chain. The chain is, however, liable to stretch, and then the teeth no longer fit accurately, and slipping is likely to take place.

In figs. 222 and 223 a good example of spur gearing is illustrated. The motor, designed by Lieut. Sprague, is intended for use on a tram car, the field-magnet being of the single horse shoe type, and of wrought-iron throughout. At the yoke end, the motor is swung from the axle of the car, this bearing being shown on

FIG. 222.

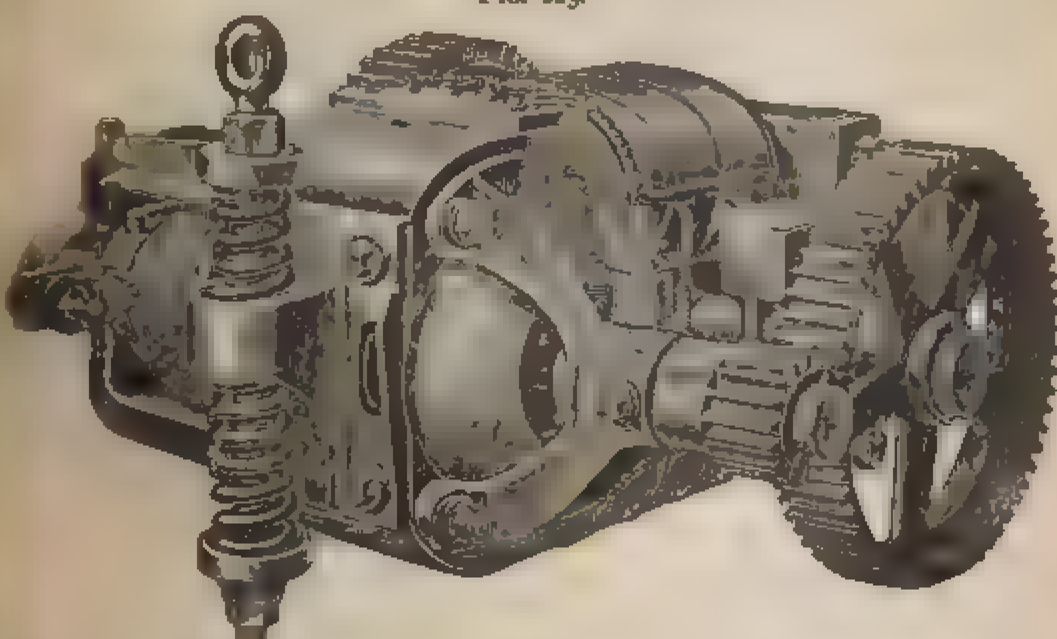


the left of fig. 222, while at the other or armature end, it is flexibly supported, being attached to the body of the car by means of the spring shown in fig. 223. Bronze brackets, fixed to the pole cheeks, support the armature bearings, and a pinion on the armature shaft, as indicated in fig. 223, gears with a spur-wheel carried on a counter-shaft which passes between the limbs of the field magnet. At the other end of the counter-shaft is the pinion, visible in fig. 222, which gears into a spur-wheel keyed on to the axle of the car, the number of teeth being so proportioned that the speed of rotation of the axle is about one-twelfth of that of the armature.

The pinion on the armature shaft is sometimes made of

hard vulcanised fibre. The wear is, of course, greatest at the teeth of this pinion, while the greatest power is transmitted by the teeth at the other end of the train. The teeth are, however, strong enough to resist a *steady* pressure far greater than can be given by the machine; were the full power suddenly applied with a jerk, the strain would be enormously increased, but a most important function of the supporting spring is to prevent this taking place, by yielding slightly when the pressure is suddenly applied. But the advantage gained in this way entails the disadvantage that the distance between the centres of the engaging wheels is liable to variation. Consequently, involute teeth are

FIG. 223.



employed, that is to say, the form of the rubbing surfaces of the teeth is the involute of a circle, such teeth being the only ones which are independent of an alteration in the distance between the centres of the wheels.

The armature is entirely covered with a waterproof material, and the field-magnets being also protected by an impervious covering, the machine is but little liable to injury from moisture.

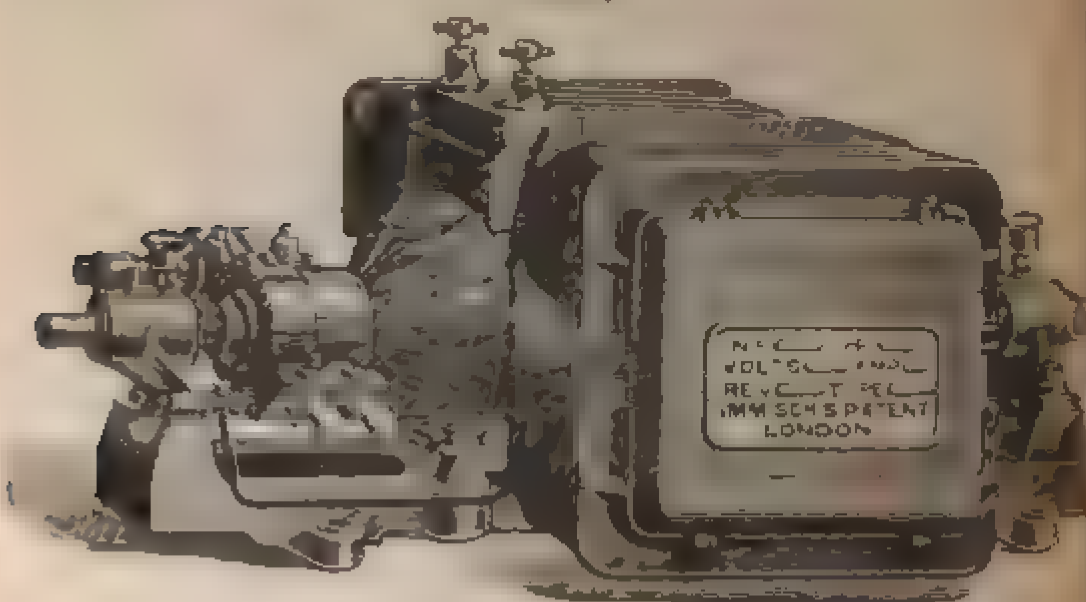
The covering of the field magnets consists of sheet copper, the joints being carefully sealed. An advantage attending this arrangement is, that the heavy current induced in the low resistance copper sheathing reduces to a very great extent the magni-

tude of the extra current developed in the coils on suddenly breaking the circuit.

Carbon brushes are employed, the commutator being of the usual form, viz. copper bars insulated with mica.

In fig. 224 is illustrated the Immisch motor, a type which is in extensive use, and possesses some important peculiarities. The field magnets are of the double horse shoe form, the coils being wound in four sections on the horizontal portions of the core, although in a few instances two coils are employed, wound on the vertical limbs, as in the case of the Manchester dynamo.

FIG. 224.

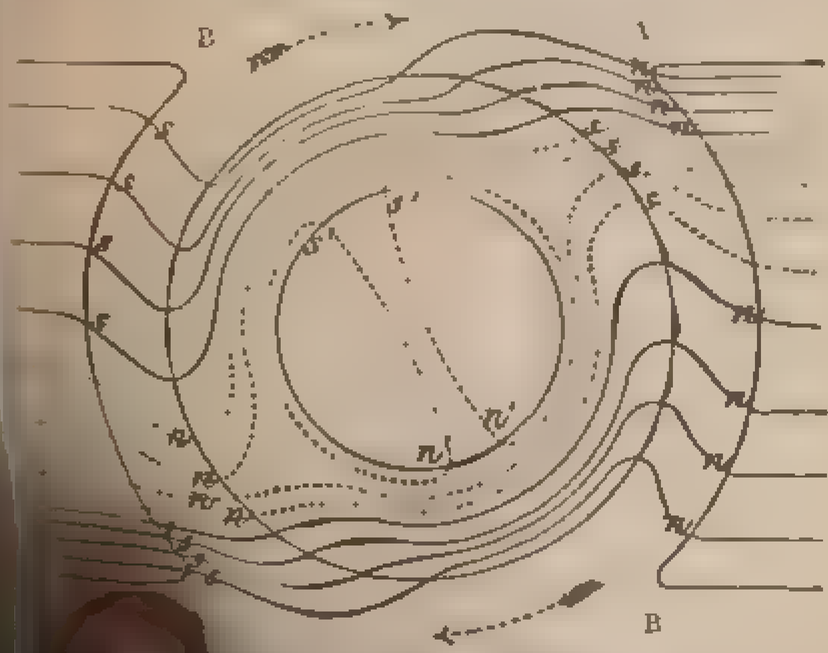


In these machines the magnetic field developed by the armature is comparatively powerful, being equal to, or even greater than, that developed by the field magnet, the object being to effect a great reduction in weight. As has been already remarked, it is possible, since the two fields reinforce each other, to employ a weak fixed field and yet obtain the necessary torque on the armature, provided the armature field is correspondingly increased in strength; but this entails some special device to avoid the necessity for altering the lead of the brushes to suit the variations of the current caused by a varying load. The actual requirement is, of course, to keep the direction of the resultant field unaltered, so that the brushes shall always be on a diameter at right angles to this field, and in the Immisch machine the armature

distortion of the field observed when a machine is used
erator also occurs when it is employed as a motor, because,
e brushes are at zero, the lines of force of the armature
at right angles to those of the field-magnets. But the
n of the current, and therefore of the lines of force, being
in the case of a motor armature, the direction of the
field is also different. The amount of the distortion
s, obviously, upon the relative strengths of the two fields.
ry slight when the field-magnets overpower the armature,
ll cases the direction of the resultant field is such that the
must be shifted *backward* to place them on a diameter
angles to the lines of force, and so to avoid sparking.

distortion of the field of a motor is illustrated in fig. 220,
hould be compared with the corresponding figure (156) for

Fig. 220



...nsity of the lines of force is greater at the
...armature is appro...g, and, as a conse-
...distribution of i... the armature core
...rents and d... more heat at these
...B from whi... mature is receding,
... With an ... rmature, however,
... and in ... s influenced to a
... curr... ir is drawn in at

at intervals, and having projections above the surface of the rest of the core, which act as driving horns.

The machines are usually series-wound, and are made in a variety of sizes for different purposes. One, designed for driving a tram-car, weighs $5\frac{1}{2}$ cwt., and is intended to run at 1,000 revolutions with a current of 40 amperes at 60 volts. The gearing consists of two steel chains with a counter-shaft, the reduction of speed being 10 to 1; the velocity of the chain on the armature shaft is, at times, as high as 2,000 feet per minute, the high speed of the motor allowing a considerable reduction in the weight of the machine. The current is supplied by eighty secondary cells carried on the car, a switch being provided for connecting these all in series, or forty in series and two in parallel, so as to vary the power given to the machine. The same switch can also be used to throw resistance in circuit, when the motor is being started, to prevent the passage of a too heavy current. The direction of rotation is reversed by reversing the current through the armature, two sets of brushes being provided, operated by a suitable lever, one set adjusted with a slight negative lead in one direction, and the other set with a corresponding lead in the reverse direction.

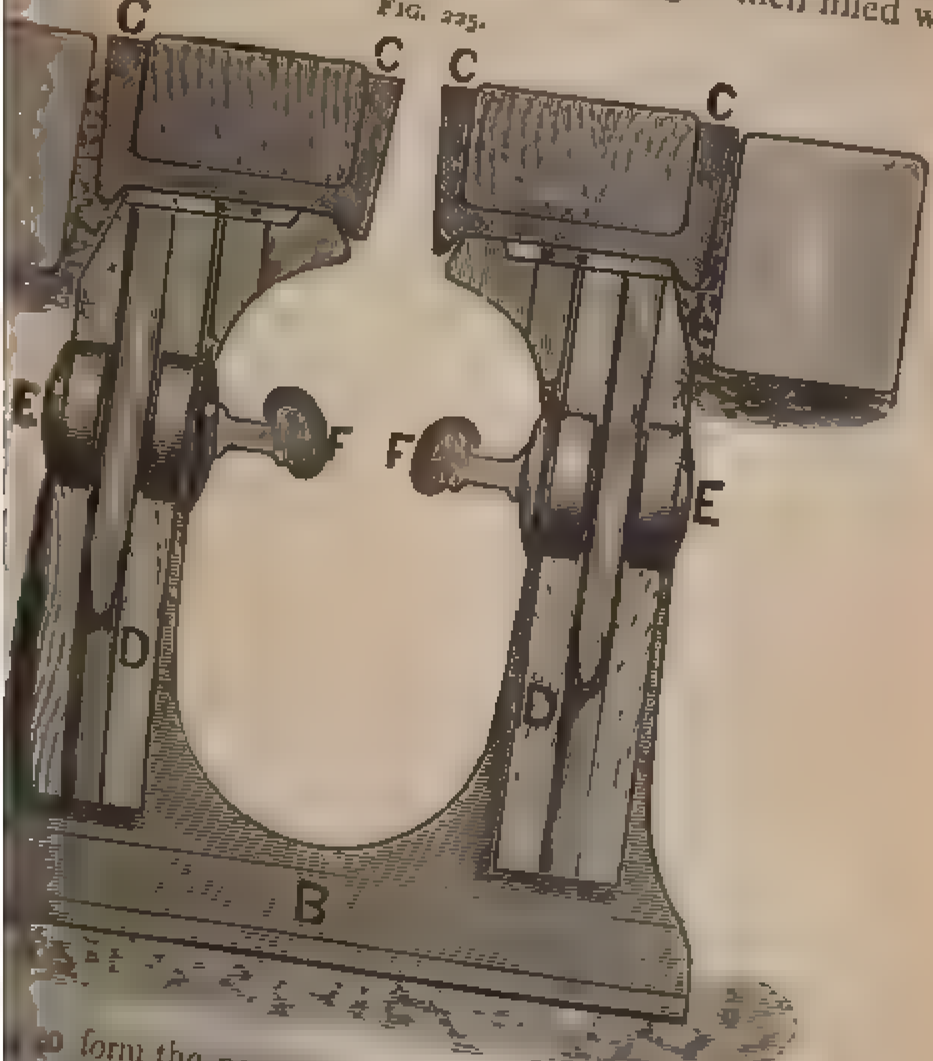
One of the earliest and most successful applications of the electric motor was made by Mr. M. Holroyd Smith, on the Blackpool Electric Tramway. This venture was made in the experimental days of electric traction, and great difficulties have been contended with and overcome. The working has been so successful under somewhat trying local conditions as to prove that the system is sound, and we shall accordingly briefly describe the main features. The line is two miles in length, and consists chiefly of a single track with a number of pass-byes. It runs along the sea-coast in such an exposed position that the road is occasionally flooded during the winter months, and at all times the saline deposit, which is always prevalent near the coast, considerably enhances the difficulty in insulating the conductors.

The conductors are laid underground in a channel midway between the two rails on which the car wheels run, the current being taken from them to the motor, by means of a collector trailing through a narrow opening in the top of the channel.

In fig. 225 a transverse section of this channel is shown, the

pport being afforded by cast-iron chairs which are fixed at
s of a yard. One of these chairs, B, is shown in the
its height is 11 inches, base $12\frac{1}{2}$ inches, and internal width
es; it has vertical slots cast in it, on each side, and into these
fitted stout creosoted boards, D D, which form the sides
hannel. Steel troughing C C, runs along and is bolted to
of the cast-iron chairs. This troughing is then filled with

FIG. 225.



o form the paving of the road; the remainder of
also of wood. The sides of the steel troughs
that the ope[illegible] ween them widens from half
to one in[illegible] tom, in order that a stone
[illegible] ed in. The conductors
[illegible] pe shown at F F; the
[illegible] d rod, 0·575 inch in

hole is also bored in the w
into this a wooden peg is dri
the groove, locks the insu
cemented into a porcelain

The conducting tubes a
of drawn brass (not shown
together, exactly fit the insi
being wrapped with wire to
left between the ends of adj
expansion and contraction, w
the connecting wedges can
pansion due to the differenc
would crack the solder. Th
positive lead, and the colle
one terminal of the motor,
the wheels of the car, the r
rails, or, rather, through the
connected at every hundred
sheathed copper wire, place
bottom of the channel. Th
be taken as that of the two t
good earth there will be p
negative terminal of the mot
rarely or never happen, and

also, the E.M.F. develop[illegible] the maximum E.M.F. [illegible] amperes. The two [illegible] parallel.

The maximum [illegible] line, is about 220 [illegible] extremities. The [illegible] sometimes so great as [illegible] been standing idle [illegible] leakage has been known [illegible] the heavy current rapidly [illegible] ments have since been [illegible] soon does not, under ordinary [illegible]

A good idea of the [illegible] gathered from fig. 226. The [illegible] equally well in either direction [illegible] ploughs of tempered steel [illegible] plates to a centre-piece. The [illegible] iron cheek, bearing on the [illegible] having fixed vertically through [illegible] insulated and protected [illegible] through the slot. The [illegible] to it a short horizontal beam [illegible] curved hard metal wings [illegible] partly embracing one of the [illegible] combination which is flexible [illegible] as those at crossing points, is [illegible] any slight obstruction, and ensures good [illegible] contacts. Each of the steel [illegible] to which is hooked a hauling rope. [illegible] car, but a loop of weaker cord is [illegible] meets with a serious obstruction [illegible] on, and can be quickly brought to a [illegible] breaks. The loop slips off the [illegible] electrical connection is also provided [illegible] to form a heart shaped terminal, which [illegible] but requires a rather sharp jerk to release [illegible]

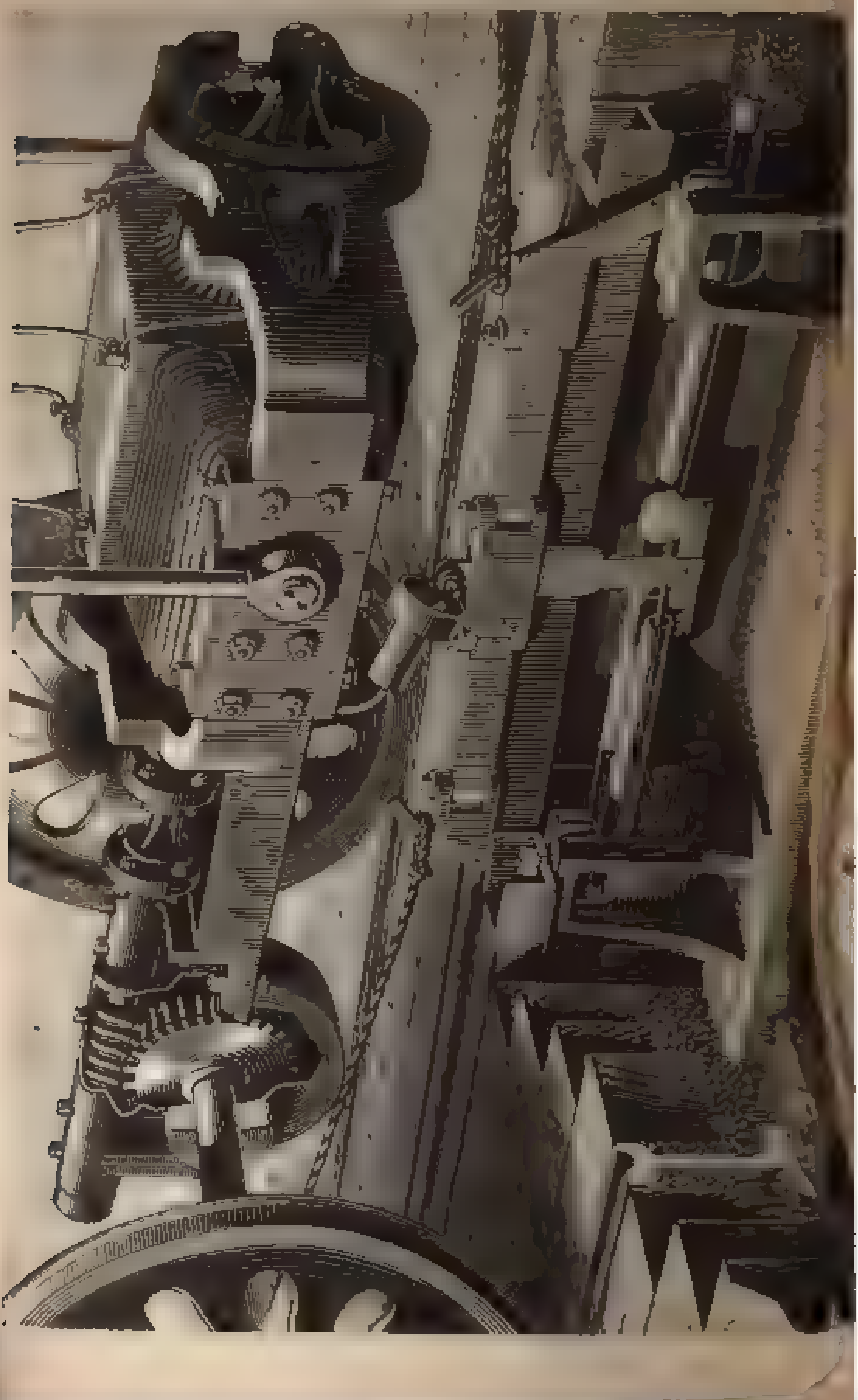
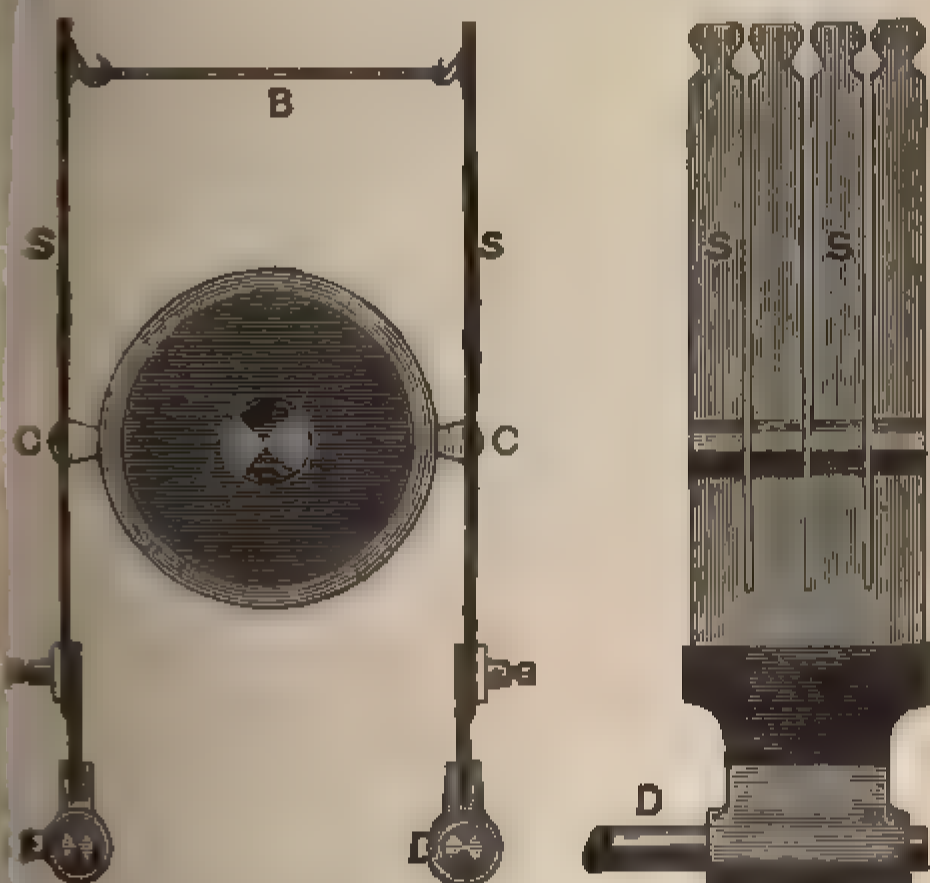


FIG. 328.

nection with motors, motor regulation and gearing. He s, in most cases, to work with series motors supplied at an ximately constant potential, and those employed on the pool line have proved very successful. Good wrought-iron ployed, but no practical advantages have been sacrificed for ke of obtaining an extremely light and electrically efficient r. The field magnets develop a very powerful field, and the between the iron of the armature core and the pole-faces is

FIG. 227.



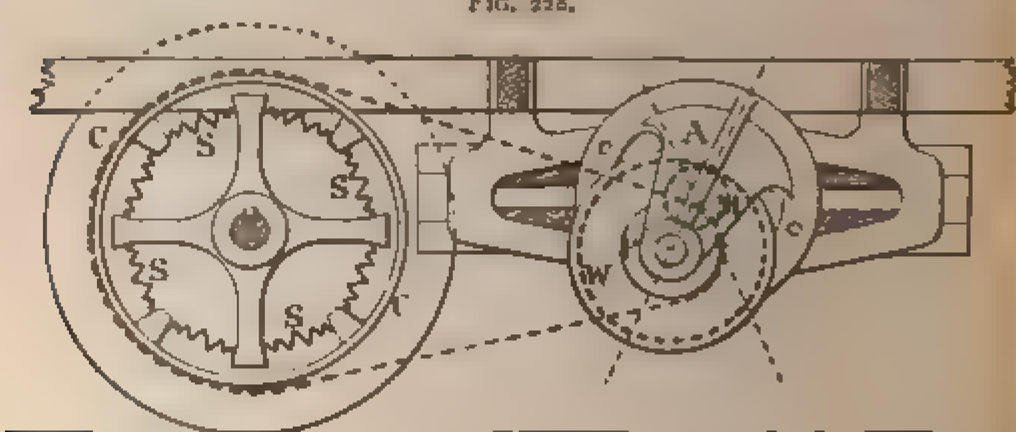
small, the armature conductor consisting of one layer of silk-red wire; consequently a comparatively weak armature field be employed, and the distortion is practically nothing. In the brushes can be allowed to make contact at the same place ither direction of rotation, without any appreciable sparking. admits of the employment of an extremely simple and effec-type of brush, which was invented by Mr. Smith for the pur-of enabling the armature to be run in either direction without

any alteration of the brushes, and to avoid the jolting of the car breaking contact.

Two views of these brushes are given in fig. 227. D D are the spindles passing through the holders to which electrical connection is made, S S being a thin flat steel spring, divided into four strips. The extremities of the springs are connected and drawn together by india rubber bands B, and a small block of a special metal, C, is fixed to the middle of each strip, forming the contact with the commutator. This type of brush is, perhaps, the simplest and most effective that can be devised for the purpose; the wear takes place at the hard metal contact-pieces, which are so fixed that they can easily be taken out and replaced.

Fig. 226 illustrates the system as applied to a line in France, and an important feature is the worm-gearing. An endless screw gears

FIG. 228.



with a wheel keyed on the axle, and the screw is connected to the armature spindle by a flexible joint, a certain amount of play longitudinally being also provided for. The screw and wheel are effectively protected by a casing, part of which is, in the figure, removed to show the interior. This gearing is now usually employed by Mr. Smith, but that devised by him for the Blackpool line is remarkably good, and is still in use there.

The latter arrangement is clearly shown by the diagram in fig. 228, for permission to reproduce which we are indebted to the Council of the Institution of Mechanical Engineers.

A side view of the motor is shown, and M is a pinion at the end of the armature shaft, gearing into an internal toothed wheel, W, that is, a wheel having teeth on its inner periphery. The

tch-circles of M and W are indicated by the dotted circles. On e outside of W, that is, on the side remote from the motor, is ed a chain pinion, P, gearing by a chain with a chain-wheel, C, hich is carried on the car axle.

The chief objection to the use of chain gearing is that the ain always gets slack after a time, but a very simple and effec- e arrangement is introduced to take up the slack and so over- me this objection. The wheel W is carried by an adjustable cket or arm, A, which is centred on the motor shaft, that is to y, the arm is capable of being rotated about a centre which actly coincides with the centre of the shaft. Consequently, the nion M and the wheel W remain in gear for every position of the m, because the distance between their centres remains unaltered. he arm is locked in position by bolts passing through slots, and is an easy matter to loosen these, rotate the arm through a all angle, and fix it in the new position if the chain becomes ack. The placing of a new chain in position also becomes a ery easy matter.

A special device is also introduced to avoid a jerk at starting, hich, as has been remarked, throws a severe strain on the gearing. he connection between the chain-wheel and the axle is not rigid, ut is made through several stout spiral springs which yield and ke the jolt off the chain when great pressure is suddenly applied. he chain-wheel C C consists of a loose annular rim, having four wardly projecting pieces placed midway between the arms diating from the hub which is keyed on to the axle. The ds of the arms are connected to the wheel C by spiral springs s, as shown in the figure, and these springs extending allow the essure to be applied more gradually.

The motors are series wound, and supplied at an approximately onstant potential, and the speed is regulated by the alteration of sistance joined in series with the motor; for, supposing the load be constant, any increase of resistance reduces the current owing through the armature and field-magnet coils, and so duces the speed of rotation; while a reduction of resistance lows the current to increase, and therefore also the speed. The me resistances can also be used to regulate the strength of the rrent required in starting. The aim has been to make the

arrangement thoroughly practical and workable without risk of error or damage by an inexperienced driver, and also to allow the variation of resistance to be made gradually, without employing a large number of coils. It is also necessary to provide a large surface for radiation in the case of the lowest resistances, because they have to carry a heavy current, and the heat generated is considerable. All these points are effectually provided for without introducing any complication whatever. The switch is in the form of a wooden cylinder with brass strips of various lengths on its circumference, which make reliable rubbing contact with steel flat springs, when the cylinder is rotated by an ordinary lever. Only four coils of about 1 ohm resistance each are employed; and by moving the switch lever the following nine changes can be made in the motor circuit, either rapidly, or slowly, step by step, as desired. The coils are denoted by A, B, C, D.

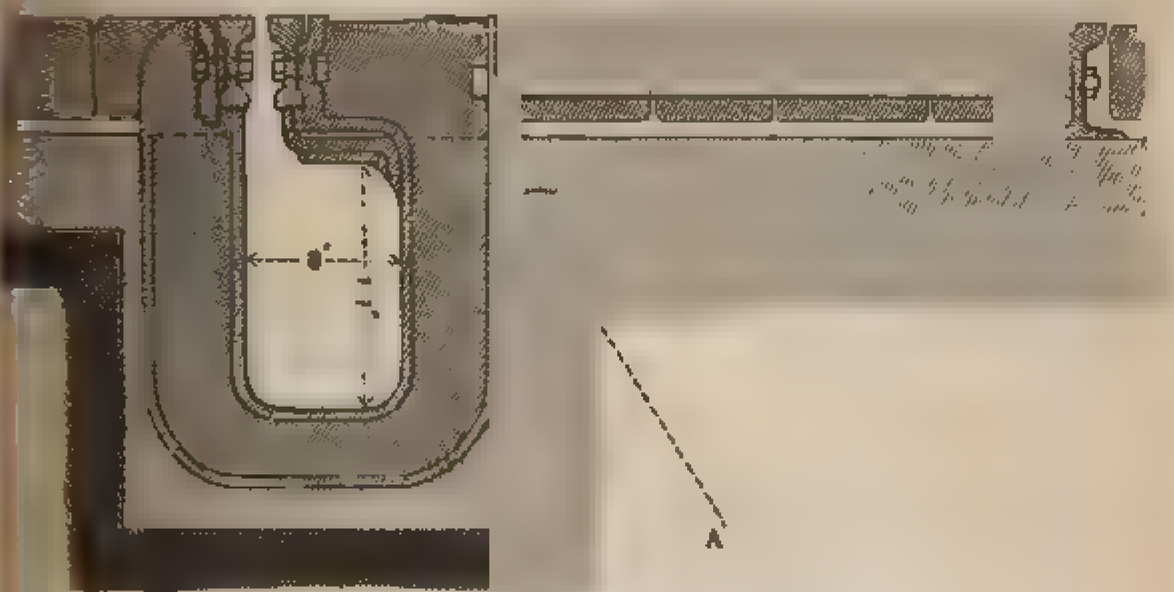
1. Circuit disconnected.
2. A, B, C, D in series.
3. A, B, C "
4. A, B "
5. A
6. A, B in parallel.
7. A, B, C "
8. A, B, C, D "
9. Resistance coils short-circuited.

It will thus be seen that not only are the lower resistances obtained without employing extra coils, but when the heaviest current is passing the heat generated is being spent upon the whole of the mass of the metal employed.

It is very significant that probably the best practical work in connection with electrical traction should have been accomplished by a man who is primarily a mechanical engineer. His success is chiefly due to the practical nature of his work, everything being designed to suit the conditions under which it is intended to be employed, and the capacity of the people who are to make use of it. He has also devised an 'overhead' system, in which the current is led to the motor by a flexible conductor, attached to a collector which slides over two parallel overhead conductors. Such

are placed cast iron yokes or chairs, to the tops of which the two rails are bolted, the walls of the conduit between these yokes being formed of Portland concrete cement. An earthenware tube, 3 in. in diameter, is embedded in the concrete, as shown at A, and in this are placed cables forming the main conductors, the

FIG. 229.



cables employed being insulated with ozokerised rubber, and having an insulation resistance of 7,500 megohms per mile. One cable, marked 'line' in fig. 230, is unbroken for the whole length of the road, while the other is divided into lengths of about 21 ft. The rails also are 21 ft. in length, and on both sides of the joint

FIG. 230.

are placed yokes, 1 ft. 5 in. apart, a chamber being formed in the space between them. In each of these conduit chambers is placed an arrangement known as the 'spring-jack' (illustrated in fig. 231), consisting of a pair of glazed earthenware blocks, supported by brackets, cast on to the joint yokes, the blocks facing

each other on opposite sides of the tube. To each block is attached, by means of a double spiral spring, a gun-metal casting curved at the ends, but flat in the centre, the springs being of sufficient strength to press the two castings together with a force of 6 lb. Two terminals are fixed on the outside of the left-hand block, each being electrically connected to one of the gun-metal strips as shown. The ends of that cable which is divided into 21 ft. lengths are connected to these terminals, so that throughout the whole of the line the gun-metal strips are in series with, and form part of, the circuit of the divided cable (see fig. 230). The current passes from one strip to the other, then by a length

Fig. 231.

of cable to the next spring-jack, and so on; it is led to the motor by forcing two conductors between the strips, these conductors being insulated from each other and joined each to one of the motor terminals.

This collector, or 'arrow,' as it is termed, is suspended under the car, and extends for its full length. It consists of two thicknesses of india-rubber belting, each having a broad brass strip riveted to it for nearly its entire length, and the nose at each end is shod with wrought-iron brought to a knife-edge, so as to easily force its way in between the two faces of the spring-jack. The maximum thickness of the arrow is 1 in., which is consequently the extent to which the gun-metal cheeks are separated. The conductor on each side of the arrow is lapped round one end, and an insulated space is left, slightly greater than the surface of

contact of the spring-jack, near the extreme ends on opposite sides, as will be seen by the diagram in fig. 230, where *a* is the arrow, and *b b* the insulated spaces. In the position there indicated, the current passes from one contact strip of the spring-jack B^2, through the motor, to the opposite strip of the next spring-jack B, the strips B^1 B^1, together with the connecting length of cable between them, being cut out of circuit.

A moment later the collector will have left the spring-jack B^1 B^2, and the contact strips will fly together and complete the circuit, while the current will pass from the other strip B^1 through the motor to B, so that the current is never cut off, nor is the motor short-circuited.

The contact surfaces of the spring-jacks are placed in the middle of the conduit, and the collector arm is bent round, so that the collector also travels along the middle of the conduit; consequently the contact surfaces, not being directly under the slot, are fairly well protected from dirt or water entering from the roadway. Suitable outlets are provided for the escape of water and for the removal of any sand, stones, &c., which may accumulate, this latter operation being made easier by the fact that the conduit is empty except at the spring-jack chambers. The constant rubbing of the surfaces of the opposing gun-metal strips keeps them bright and ensures good contact when they are pressed together by the springs.

The motors are supported at one end by two bearings on the axle, and suspended at the other end by a spiral spring attached to a stout beam across the frame of the car. The speed of the motors is unusually low, viz. 400 revolutions per minute, the object being to avoid the use of a countershaft.

Worm-gearing is employed, reducing the speed in the proportion of 9 to 2; a double helical pinion on the armature shaft gears with a worm-wheel keyed on the axle, so that this wheel advances one tooth for every two complete revolutions of the armature.

The machines are series wound, and the regulation is controlled by two massive switches placed on the driving platform. In order to reverse the direction of rotation, the connections of the field-magnet are reversed by means of one switch; while the other varies

the value of a set of resistance coils, which are joined up as a shunt to the field-magnet coils, and afford a means of weakening or strengthening the field according to the power and speed required.

The current through the armature being kept constant, the maximum power is obtained when the field-magnets are unshunted and take the whole of the current, and this arrangement would be adopted for mounting an incline, while, if less power is desired, the field can be weakened by shunting the field magnets. The shunts are arranged to provide for three speeds, and, in order to stop the car, the field-magnet is short-circuited, the current still passing through the armature.

In starting a motor worked on the parallel system, there is sometimes a risk of the armature being damaged by the passage of a heavy current; for there is a constant potential difference maintained at the terminals sufficient to determine a dangerous current, should the armature fail to quickly get up speed and develop an opposing electro-motive force. No such danger exists in the series system, the current strength being constant under all conditions.

In the case under notice a Statter constant-current dynamo is employed for the purpose of generating the current. The method by which the regulation of this machine is effected has already been fully described.

The pressure at the terminals varies from a small value up to nearly 500 volts, according to the demand made by the motors; and a considerable difference is made in the power expended by reversing the field magnet connections on the car, when it is running down hill and when no power is required. The effect of this is to turn the machine into a generator for the time being, its E.M.F. *assisting* that of the main generator and reducing the demand made upon the latter; so that a large amount of the energy stored in the car during its journey up hill may be usefully employed, instead of all being wasted as heat at the brakes, and when a large number of cars is employed on an undulating line, this becomes an important advantage. It should be observed that although a motor supplied at constant potential, in parallel circuit with others, may dam back the current when the speed

in running down-hill, and so absorb less power, yet it cannot ly assist the source of supply in feeding the circuit, until the becomes sufficient for the machine to develop an E.M.F. than that maintained by the generator.

n important operation in connection with a dynamo-machine determination of its commercial efficiency; that is, in the case generator, the ratio of the electrical power appearing in the al circuit and available for useful work, to the total mecha- power spent in driving the machine; and, in the case of a , the ratio of the useful mechanical power obtained on the re shaft to the total electrical power absorbed. The accurate rement of the mechanical power in either case presents difficulty. The usual method is to employ a transmission ometer, or a friction brake, to determine the horse-power ded or obtained, as the case may be, but it is not possible either class of apparatus to be certain of obtaining any but proximately correct result. The electrical power, on the hand, can be measured with extreme accuracy, it being necessary to find the current strength in, and the potential nce at the extremities of, the external circuit of a generator; e current passing through a motor, together with the E.M.F. terminals; the product of the two quantities in either case, the power in watts.

it were possible to arrange matters so that it would become ial to measure, by a mechanical process, only a small fraction total mechanical power given to a generator, say one tenth her nine-tenths being measured electrically), then a much accurate result might be obtained; for any error made in ring this fraction, when distributed over the whole amount, have but one-tenth the value of that which would other- ccrue. And, further, it is far easier to accurately determine lue of a small, than of a fairly large amount of mechanical

important departure, rendering such a method possible, ade some time since by Dr. Hopkinson. He takes two imately equal machines, and, driving one as a generator, wires from it to the other, so connected that the current ped by the first machine drives the second as a motor

Now, the power appearing on the motor shaft is less tha
spent on the generator, by an amount equal to the power ab
by friction, by the heating of the various conductors, an
cores, &c., in the two machines.

But the power which does appear on the motor shaft might
be employed to assist in driving the generator; and this is eff
by the simple process of rigidly coupling the shafts of the
machines together; so that, then, the only mechanical p
required to be supplied and measured, is an amount equal to
just referred to as being wasted in the various parts during
double conversion.

This fraction, thus supplied, is conveniently measured b
dynamometer of the Hefner Alteneck type, which mea
directly in pounds the difference between the pull on the t
and slack sides of the belt, that is, the actual pull causing
rotation of the pulley. This number, multiplied by the numbe
feet travelled by the belt per minute, gives the number of f
pounds of work performed in one minute, which, divided by 33,0
gives us the horse-power supplied by the belt; since one ho
power is a rate of working equal to 33,000 foot-pounds per mi
With the particular dynamometer employed in one test made
Dr. Hopkinson, the pointer moved over one division of the sc
for a pull of 2·705 lb. on the tight side of the belt in excess
that on the slack side, and the radius of the pulley was such th
one revolution corresponded to an advance of the belt thro
3·63 feet; in this case, then, the work done per revolution w
2·705 × 3·63 foot pounds, for one scale-division.

From this it will be seen that if T represents the number
scale divisions traversed by the pointer, and n the number
revolutions per minute, then the power applied $= \frac{2\cdot705 \times 3}{33{,}000}$
$\times n \times T = 0\cdot000298 \times n \times T$ horse-power.

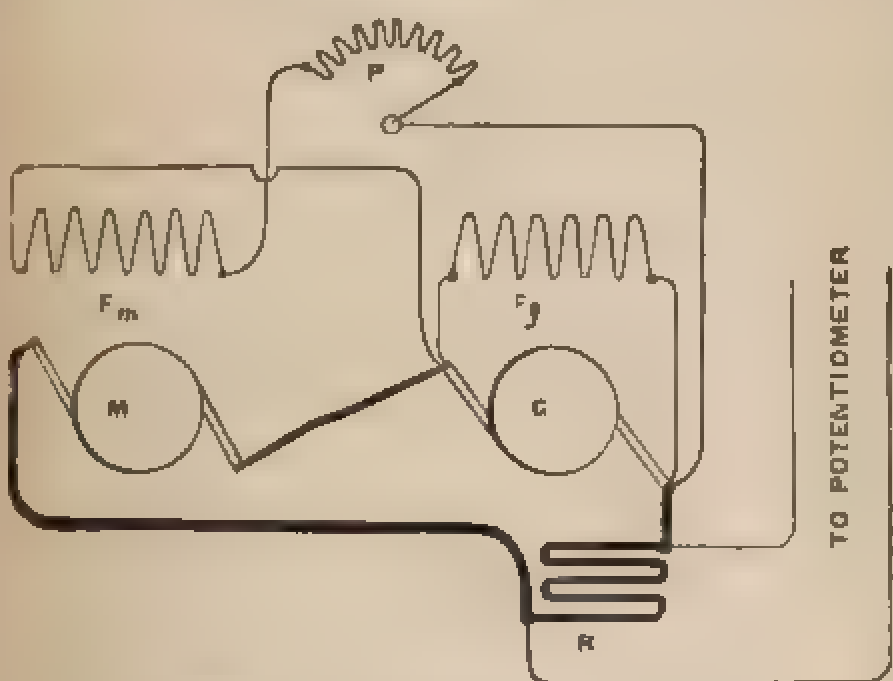
A number of experiments were made with the machines in
case under notice, and, as they are interesting, the full results
one test, as furnished by the experimenter, are appended.

The electrical connections were made as in fig 232, where
and Fg represent the armature and field-magnet of the generat
and M and Fm those of the motor. The heavy lines indicate th

main connections between the two machines, and, in order to measure the current, a small accurately known resistance, R, is placed in the main circuit; to the extremities of R, are connected wires leading from a potentiometer, by means of which, with a Clark standard cell, the potential difference between the ends of the resistance can be accurately measured.

This potential difference, divided by the resistance (which was in this case 0·0058 ohm), would give the current flowing through

FIG. 232.



the main wire. The potential difference between the terminals of the generator was measured by a Thomson graded voltmeter, previously standardised by a Clark cell.

Now, the two machines were exactly alike, and, consequently, if joined in opposition (as two shunt machines must be, when one is required to drive the other), and then driven at equal speeds, no current would flow from one armature to the other, for they would generate equal E.M.F.'s, or, in other words, the counter-electro-motive force of the motor would be equal to the electro-motive force of the generator. For this reason, it is necessary to weaken the strength of the motor field, and this was effected by placing a set of variable resistances, P, in series with the motor field magnet coils; and, by altering this resistance, the current

passing through the motor armature could be varied at pleasure. The motor field magnet coils, together with P, form a shunt to the generator terminals; the motor armature thus receiving the whole of the current passing through R. And, since the resistances of the two field magnet circuits are known, the current in each can readily be calculated after the potential difference at the generator terminals has been measured.

The resistances of the armatures and field magnet coils of the two machines were :—

Generator . .	Armature . .	0·009947 ohm.
	Field-magnets .	16·93 "
Motor . . .	Armature . .	0·009947 "
	Field-magnets .	16·44 "

1. The two dynamos were run with brushes removed and with the fields unexcited.

Scale reading = 21·6 divisions.
Revs. per minute = 808.
Horse-power = 5·2.

2. The two fields were separately excited, and the dynamos driven, still with the brushes off, when

Scale reading . . . . = 30 divisions.
Revolutions . . . . = 802.
Shunt current in field of generator = 6·9 amperes.
" " " motor . = 6·7 "
Horse power . . . . = 7·16.

3. The connections were made as in fig. 232, and the following results were obtained :—

E.M.F. at terminals of generator .	= 110·12 volts.
Main current	= 358 amperes.
Current through generator magnets	= 6·50 "
Current through motor magnets .	= 5·36 "
E.M.F. at terminals of motor . .	= 107·33 volts.
Speed of machines . . .	= 764 revs. per minute
Power transmitted by belt . .	= 6602 watts = 8·850 h.p.

...ence—

...power given to generator . = 42917 watts = 57·53 h...
...r lost in armature core . . = 831 " = 1·11
...r lost in generator magnets . = 716 " = 0·96 ,
...r lost in generator armature . = 1360 " = 1·823 "

...d therefore—

...Commercial efficiency . . . = 93·23 per cent.
...oss in core . . . . = 1·94 "
" magnets . . . . = 1·66 "
" armature . . . . = 3·17 "

...arly for the motor—

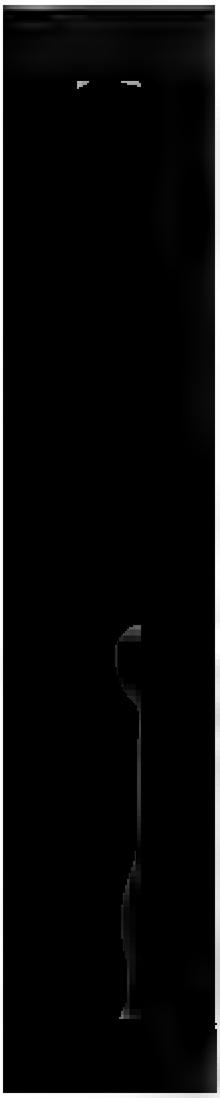
...wer given to motor . = 38886 watts = 52·13 h.-p.
...st in internal friction of . . . . = 831 " = 1·11 "
...t in motor magnets . = 472 " = 0·63 "
" armature . = 1275 " = 1·70 "

...erefore—

...mercial efficiency of motor . . = 93·37 per cent.
...in core . . . = 2·14 "
magnets . . = 1·22 "
armature . . = 3·27 "

...s due to friction of the bearings and one or two un-
...auses, has then to be determined and deducted, to
...eal commercial efficiency, which, after this deduction,
...o be: motor 92·6 per cent., and generator 92·5 per

...ficiencies are phenomenal ... would seem to indicate
... measurement; but th... itself, being a good
...eful attention on the ... student.
...ntage of the original ... that it is necessary
...oximately similar m... order to perform
... sometimes inconve... ber of modifi-
...have, however, bee... the measure-
... the power me... ...g in some



e used to [illegible] the field-magnets. [illegible] coupled [illegible] through and [illegible] a small [illegible] When the [illegible] e is to be started [illegible] the exciter [illegible] which puts the [illegible] as synchronism between the [illegible] d, the former is [illegible] e extremely good [illegible] ors when used as motors, [illegible] ed for classes of work [illegible] ried, or where frequent [illegible]

n these motor properties [illegible] nt fact that two [illegible] run in parallel, that is to say [illegible] in parallel so that the two [illegible] to the external circuit. It is, however, [illegible] chines shall give the same [illegible] phasally, that is to say, the [illegible] force, and also the maximum [illegible] two machines must coincide in point of time. Then ltant E.M.F. is the same as that of one, while the current, o the power developed, will be doubled. Now the remark- ct is, that the two machines will make great efforts to keep e, and will do so, even if the mechanical power supplied to increased or diminished within a reasonable limit. To this extremely important mutual action we may remember e reaction between the armature and field magnets of a current dynamo is such as to tend to stop the rotation, and ndency becomes stronger as the current in the armature ses, while a weakening of the current of course reduces the nce to rotation. [illegible] speed might therefore [illegible] diminished [illegible] the current [illegible] through the arm[illegible] s me [illegible] while by [illegible] opposing [illegible] rcuit, current, [illegible] ould be incre[illegible] d if [illegible] loped by the[illegible] he [illegible] versed, [illegible]

Now, these effects can be obtained with an altern dynamo. That is to say, if the brief currents generated increased in strength, the tendency will be for the machin down, while if an opposing alternating E.M.F. acts in such as to reduce these currents, the machine will quicken and it will run as a motor, doing work for the moment on mover, if the opposing E.M.F. is sufficient to determine in the reverse direction.

Now when two alternators are driven independe coupled in parallel, and one begins to lag behind the maximum E.M.F. of the leading machine occurs a mome than that of the other, and consequently a heavy curr from the leading to the lagging machine for a very brief i time This current being opposite in direction to that then being generated by the lagging machine, tends to d a motor and to accelerate its speed ; or if the difference is not sufficient to set up a reverse current, it weakens the one with the effect of allowing the lagging machine to as already explained. On the other hand, the later E.M.F. of the lagging machine will tend to increase the the leading one and so pull it up. These reactions mence immediately the alternators tend to get out of phas well-designed machines the effect is so prompt and for they run together perfectly in spite of inequalities in the It becomes very important, therefore, to decide what and peculiarities a machine should possess to fit it for working. Until recently it had been supposed that it lutely necessary for such a machine to have consider induction, but even then the performance was admitte somewhat difficult and uncertain. Consequently, an without an iron core, and with few convolutions, was deem undesirable ; but these views have been somewhat shak to a great extent, entirely reversed, by the recent researche Mordey. That gentleman starts with the assumption that maintenance of synchronism depends upon the motor prop the two alternators, the machine best fitted for parallel must be one which possesses these properties to a high de

Consequently, the armature should have little resistan

little self induction, and then the transfer of power by means ...ief currents from one machine to the other, which serves to ...en or retard as required, takes place much more suddenly, and regulating action is much more prompt and forcible. Of ...se, the armature will have some self-induction and some re...nce, but it is satisfactory to know that neither of these unde...le factors need be made abnormally high, merely for the ... of rendering parallel working practicable. It is probable, ...ever, that there is a limit depending upon other conditions, ...h as the rate of alternation,) below which it is inadvisable to ...ce the self-induction, and that some definite relationship ...een self induction and resistance should exist for any given ...; but, on the other hand, it is possible that this limit is very ... and that the working rule will be to make the two factors ...erned as low as is practicable.

In the Mordey alternator, which has no iron in the armature, ...nduction has a low value, so low, in fact, as to unfit the machine ...parallel working if the old theory were correct. In order to ...ort his views on the subject, the inventor made an exhaustive ...s of tests with two of these machines, each being similar in ...arance to that depicted in fig. 140, but having an output of ...orse-power, with a maximum E.M.F. of 2,000 volts, at a speed ...o revolutions per minute. The details of one set of tests are ...n below. It should be noted that the machines were driven ...wo independent engines, not connected in any way, and pro...d with heavy fly-wheels; each engine also drove a heavy set ...ountershafts, fitted with a number of belts, &c., so that the ...nentum was considerable.

1. The alternators were run up to full speed, and each excited ...ive 2,000 volts. When in pha... the... were switched in parallel ...hout any external load, and w... ...insertion of any self-...uction coils or resistance be... ...they ran in parallel ...fectly.

2. A considerable induct... ...varied, ...d taken off. They ran ...

3. They were unc... ...ted ...the mains, they w... ... ...parallel and on to ...

4. One alternator was excited
giving 2,000 volts. They were the
into step perfectly, giving a termin
1,500 volts. No extra self-induc
this or in any other case. A load
ing their behaviour.

5. With one machine at 1,000
they were switched in parallel wh
went into step. A large current
for a fraction of a second, but n
it to be measured or to do any h

6. They were then left runni
connected from the engine, by it
to a loose pulley. It continued
A load of lamps was at the same

7. The two machines were t
2,000 volts. They were then switch
and without any external load, a

8. Whilst running as in 7,
shut off one engine. The alter
acting as a motor and driving th
countershafting and belts. It w
the top of the belt becoming ti
machine was the motor.

To find the power exerted b
in 8, a direct current motor was
required to drive the engine a
horse-power.

The above results speak for
planation may be given with res
in excess, of 500 volts, which
enormous current through the
tures, the low self-induction no
though it is only applied in th
moment. No such dangerous
must evidently be some other c
rather interesting point has b
William Thomson, who points

ease of the current at any instant through the two armatures, in direction determined by the excess of E.M.F. of the more erful machine, is to tend to increase the strength of the field the weaker, and to decrease that of the stronger machine. So t although a strong current would be started round the two atures, its effect would be to immediately strengthen the field the 1,000-volt and oppose that of the 2000-volt machine, until E.M.F. developed by each would have nearly the same value, 1,500 volts. This brief equalising current would pass twice every complete alternation.

CHAPTER XIII.

TRANSFORMERS.

WHEN it is desired to convey energy to a distance by me electricity, either for the purpose of producing light or mech motion, the chief problem to be faced is, how to reduce minimum the waste of energy during the transmission. W seen that when a wire is used to convey a current, the which energy is lost in that wire can be measured by multi together the current strength in amperes and the differe potential between the ends of the wire in volts, the result the number of watts so expended. And since the electro-m force is equal to the product of the resistance of the wire a current flowing, the loss in watts may also be calculated product of the resistance and the *square* of the current st That is to say, in the first place the power expended in a of a circuit is proportional to the resistance of that part. pose, for example, a dynamo were employed to furnish curr a number of lamps arranged in parallel, their joint res being 10 ohms; then if the resistance of the machine and or connecting wires were also 10 ohms, exactly as much would be wasted, as would be usefully expended in the la state of affairs which manifestly could not be tolerated. resistance of the machine and leads were reduced to 1 ohm the power wasted would be one-tenth of that usefully emp and so on.

The resistance of the combination to which power has supplied is, as a rule, extremely low; and when the lamps or are joined in parallel, the current carried by the mains is e the sum of that required by the whole of them. Consequen resistance of these mains must be kept extremely low, a sma

ion of an ohm in fact, otherwise the proportion which the po wasted bears to the total quantity of power developed beco excessive. To keep the resistance low copper of high conducti must always be employed, but the practical limit as regards ional area is quickly reached on account of the high price of metal.

Speaking generally, it may be said that transmission of ene o any distance by electricity is not economical, if we depend u educing waste merely by increasing the conductivity of the lea Again stating the case as:

$$\text{Watts lost} = C^2R,$$

where R is the combined resistance of the leads and genera we see that the only other way out of the difficulty is to red the current strength.

If this can be done the advantage is very decided, for, halving the current, the power wasted in any portion of the cir s reduced to one-fourth. It may not, however, be evident at sight, how with this reduced current the same amount of ene can be transmitted in an equal time.

Digressing for a moment, in order to introduce an analogy, student will probably be aware that in transmitting power mec nically to a distance by a slowly moving cable, it is impera that the cable and the rest of the moving parts shall be very str and massive, and consequently the power lost by friction, & becomes enormous. But the energy transmitted per minute equal to the pull on the cable in pounds, multiplied by the dista in feet through which the cable moves in a minute; so that, by creasing the velocity of the cable, the strength and size of it of the other moving parts can be correspondingly reduced with reducing the amount of energy transmitted per minute. It is fact possible to transmit enormous power by means of a light w cable, if it travels with sufficient rapidity; and the loss due friction is obviously reduced with the reduction in size and wei of the moving parts. Even if it is essential for the power nsmitted, to be taken, say, from a slowly rotating wheel, i economical to transmit it at a high velocity, and effect essary reduction in speed by suitable gearing.

Somewhat similarly, very great power can be conveyed elec-cally by a comparatively small current traversing a thin wire, only the electric pressure or potential difference is sufficiently hig for the power in watts may be calculated as the product of the two factors, and no difference in the amount is made by reduc one of them, if the other is increased in like proportion.

But unfortunately it rarely happens that electrical power c be utilised at a high pressure; for instance, 110 volts is usua the maximum pressure required by a set of incandescent lam joined up in parallel, and consequently it becomes necessary employ, if possible, some arrangement which shall perform the sa function as does mechanical gearing in reducing speed That to say, we require some apparatus competent to receive electric power in the form of a small current at a high potential differenc and again give out that power in the form of a heavy current, a at a correspondingly lower potential difference.

It is possible to construct such apparatus; and before pro ceeding further we may notice the two chief points to be borne i mind in designing it:—

1. The proportions of the parts must be so calculated th the reduction is effected in the desired ratio; or, the value the resulting potential difference must be the required fraction that applied to the apparatus.

2. The loss in power during the conversion must be kept a low as practicable; that is to say, the design must be such th the efficiency of the apparatus is high.

The conversion from a high to a lower potential is rendere possible by the fact already fully explained, that by starting o stopping a current in a circuit, a brief current can be induced in neighbouring wire. The circuit in which the original current started or stopped is called the 'primary' circuit, while that i which the currents are induced is called the 'secondary' circuit

In order to obtain the maximum effect, it is necessary t arrange that the secondary circuit is cut by as many as possible the lines of force generated by the primary. The best method to wind the wire in two coils, and placing them close together provide plenty of iron in the vicinity in order to make the primary lines of force extend out beyond the secondary coil. The

...uld in fact form a closed magnetic circuit of low resistance, ...bracing both coils. But since the rapid reversals of the current ...erate eddies, the iron must be carefully laminated; in any case, ...rtain amount of power is wasted by hysteresis.

Suppose the number of convolutions in the two coils to be ...al; then by sending a rapidly alternating current through the ...mary, an alternating current of about the same strength might ... obtained in the secondary. Again, the secondary might con... of a great length of wire in many convolutions, thin wire ...ng employed to enable it to be kept near to the primary. ...this case the primary lines of force would cut the secondary ...uit many times, and the induced E.M.F. would be much greater ...n that urging the current through the primary. But since the ...er obtained from the apparatus cannot be greater than or even ...al to that given to it, a corresponding reduction in the other ...tor would be observed; in other words, while the E.M.F. had ...n enormously increased, the current would have been far ...ler than that in the primary.

The student is probably familiar with a piece of apparatus ...wn as an 'induction coil,' in which a rapidly interrupted heavy ...rent of low E.M.F. is passed through a few turns of wire, ad...ent to an enormous number of turns of finer wire. A bundle ...thin varnished iron wires serves as a core, and a very feeble ...rent of extremely high E.M.F. can be obtained in the secondary ...uit. Such apparatus has proved of extreme value in experi...ntal researches, but it can hardly be said to have any very ...at importance from a commercial point of view.

We are far more concerned with the effects obtained by pro...ding in the reverse order, viz. by making the length of the ...mary much greater than that of the secondary.

Supposing, for instance, we use the fine wire coil of an ordi...y induction coil as the primary, and the thick wire coil as the ...ondary; the former offers considerable resistance, and it will ...uire a high E.M.F. to send an alternating current of even feeble ...ngth through it. But on measuring the resulting current in ... thick wire coil (now being used as the secondary), it will be ...nd that while the E.M.F. is low, the current passing through ... low resistance circuit is comparatively very heavy. It is a most

important fact that by constructing such an induction coil so that nearly all the primary lines of force can effectively cut the secondary, the secondary E.M.F. can be made to bear nearly the same ratio to the primary E.M.F. that the number of convolutions in the one coil bears to the number in the other. Therefore, by making the resistance of the magnetic circuit, and the electrical resistance of the secondary circuit, both very low indeed, we can obtain at the terminals of the latter, an alternating potential difference whose average value is almost equal to a definite fraction of the average of the alternating potential difference maintained at the primary terminals.

For instance, if the primary consists of 1,000 turns and the secondary of 10, and a current of 1 ampere passes through the primary coil while the potential difference is 500 volts, then the secondary current may be 100 amperes, and the induced E.M.F. rather less than 5 volts. This is the important case with which we have to deal, for it thus becomes possible to effect the much desired object of transmitting electrical power at a high electrical pressure, and employing it at the required point at a lower pressure. A piece of apparatus which is capable of effecting this transformation from high to low E.M.F., is called a 'transformer'

The first transformer was constructed in 1831 by the immortal Faraday. The principles which he then discovered, of the remarkable action of a varying current upon an adjacent circuit, are of almost inconceivable importance, while the method of constructing his original transformer, which we shall briefly describe, was well abreast of the then existing practice.

Faraday procured a welded ring of soft round bar iron, $\frac{7}{8}$ inch thick, the external diameter of the ring being 6 inches. Round one part of this ring he wound about 72 feet of copper wire, $\frac{1}{20}$ inch in diameter, in three superposed helices, the distance round the ring thus covered being about 9 inches. The wire was bare, the first helix being insulated from the iron by a layer of calico, and twine was wound side by side with the wire, to prevent contact between adjacent convolutions. Then followed another layer of calico, over which was wound the second helix, insulated with twine similarly to the first, then another layer of calico followed by the third helix, the whole being covered by calico. The ends

of each helix were brought out so that the three coils could be used separately, or conjointly, in series or in parallel.

On the other half of the ring a length of 60 feet of copper wire was wound in two equal helices and insulated in precisely the same manner as before. These two coils were joined in series and connected to a galvanometer. The other three helices were also joined in series, and a battery connected up to them. The immediate effect of making this latter connection was seen in a violent deflection of the needle of the galvanometer placed in the 'secondary' circuit. The needle quickly came to rest at zero, but was deflected momentarily in the opposite direction on the battery being disconnected from the primary circuit.

The lines of force of the current in the primary coil were, of course, conducted by the iron ring round through the secondary coil, and the sudden cutting of this coil by them gave rise to the observed currents. As might be expected, however, a great many of the lines of force did not reach the secondary coil, and Faraday obtained a more violent deflection with the same primary current and shorter lengths of wire, by so arranging the two circuits that nearly all the lines of force generated were able to cut the secondary circuit. He disconnected the two helices which in the previous experiment were used as a secondary circuit, and in their place took two of the three superposed helices on the other half of the ring, joining them in series and to the galvanometer. The battery was then joined to the third helix, which formed the primary circuit, and although the lengths of wire were so much shorter, rather better effects were obtained, because of the increase in the percentage of the lines of force usefully employed. Had Faraday supplied the primary circuit with a rapidly alternating current, he might have obtained an alternating current of half the strength, and of corresponding higher electro motive force in the secondary circuit; but his galvanometer would not have indicated the presence of this current if the reversals were too rapid to give the needle time enough to move with each pulsation. By using one helix for the secondary and two for the primary, the secondary current might have had twice the strength of the primary.

We may repeat that a transformer should be so designed that it can effect the required reduction from high to low E.M.F. with

secondary, while the primary coil of thinner wire, P, P, lies outside it, and it will be observed that the depth of the layer of iron wire is about equal to the diameter of the compound coil of copper wire. Such a transformer gives fairly good results, for nearly all the primary lines of force extend out to the massive iron shell, and in so doing cut the secondary. But it is an extremely tedious and expensive piece of apparatus to make on a large scale, on account of the slow process of winding the enormous length of iron wire. Further, if a fault should occur, and faults *will* occur, it becomes necessary to remove the whole of the iron wire before the coils can be got at, to remove the fault.

Consequently large transformers are not made in the manner illustrated, although in most cases the principle is the same. The apparatus usually consists of two coils of wire, nearly oblong in shape, lying side by side, with an easily fixed, and easily removable laminated iron covering.

About thirty-three years ago a first-rate method of constructing a large transformer was patented by C. F. Varley, which may be regarded as a combination of the two types mentioned. He took a bundle of iron wires of approximately equal lengths, and over this bundle wound the primary and secondary coils. These coils were placed in the middle of the bundle, and extended along it for a distance equal to one third of its length, so that the iron wires protruded from each end to a distance equal to the length of the coil. The ends of the iron wires were then bent round over the coils, so as to meet and overlap each other, thus completely encasing the coils with iron, except at one place through which the connecting wires were led.

But the necessity for large transformers did not then exist, and the method was scarcely at all employed. It is, however, somewhat extensively used at the present time, because of the ease with which the iron shell can be fixed or removed. The highest practical development of this type is seen in the Ferranti transformer, which is now doing heavy work in London. A general view of a Ferranti transformer, designed to receive about fifteen electrical horse-power at a high potential difference, and yield a large percentage thereof at a lower potential difference, is given in fig. 234. A quantity of hoop-iron, divided into six bundles, forms

and is handled, every precaution must be taken to insulate it from the primary. For this reason the two ever interlaced, but are wound separately, with effective between them.

mplest way of laminating the iron core, is to build it up on wire, in exactly the same manner as the core of a ing. In fact, a Gramme ring armature having a large f convolutions can be readily turned into a very fair r, by using two or three equidistant sections for the coil, and the remainder in series for the primary. ers are sometimes so constructed in sections, but the is to wind the wires spirally in two continuous coils.

pid reversals of magnetisation which take place, quickly on core, however well it is laminated. This heat must d since is enve- copper, must be to the efore it the ex- . This the con- very un- and for several

Fig. 233.

ons it is preferable to place the iron outside instead of wire, the position of the iron being quite immaterial, it can act effectively in leading the lines of force through d paths.

233 is illustrated one method of constructing such a . Its external appea is that of a massive ring of al diameter, and in t e is shown a section taken iameter, at right ang plane of the ring. The secondary coils are l in a single coil, and concentrically apped round with an al, and over pirally an enormous n wire. The ck wire, S S, is the

The magnetic circuit of many transformers is now built up of a number of flat plates of sheet iron, placed so that the plane of the sheet shall be as far as possible parallel to the direction in which the lines of force are thrust through the iron. They are usually insulated by a thin coating of varnish, or by paper, or sometimes calico, and the devices by which such plates may be cheaply made and placed in position are very numerous. As they differ but little in principle, we need select only two patterns for description.

Fig. 235.

Two general views of the Mordey type of transformer are given in fig. 235. The thin iron plates are oblong stampings, and an oblong strip is stamped out of the middle of each, exactly equal in length to the breadth of the original plate. When

[illegible] the [illegible] to form the [illegible] is [illegible] slipped over the [illegible] from the [illegible]. The [illegible] are then [illegible], as shown in the [illegible]

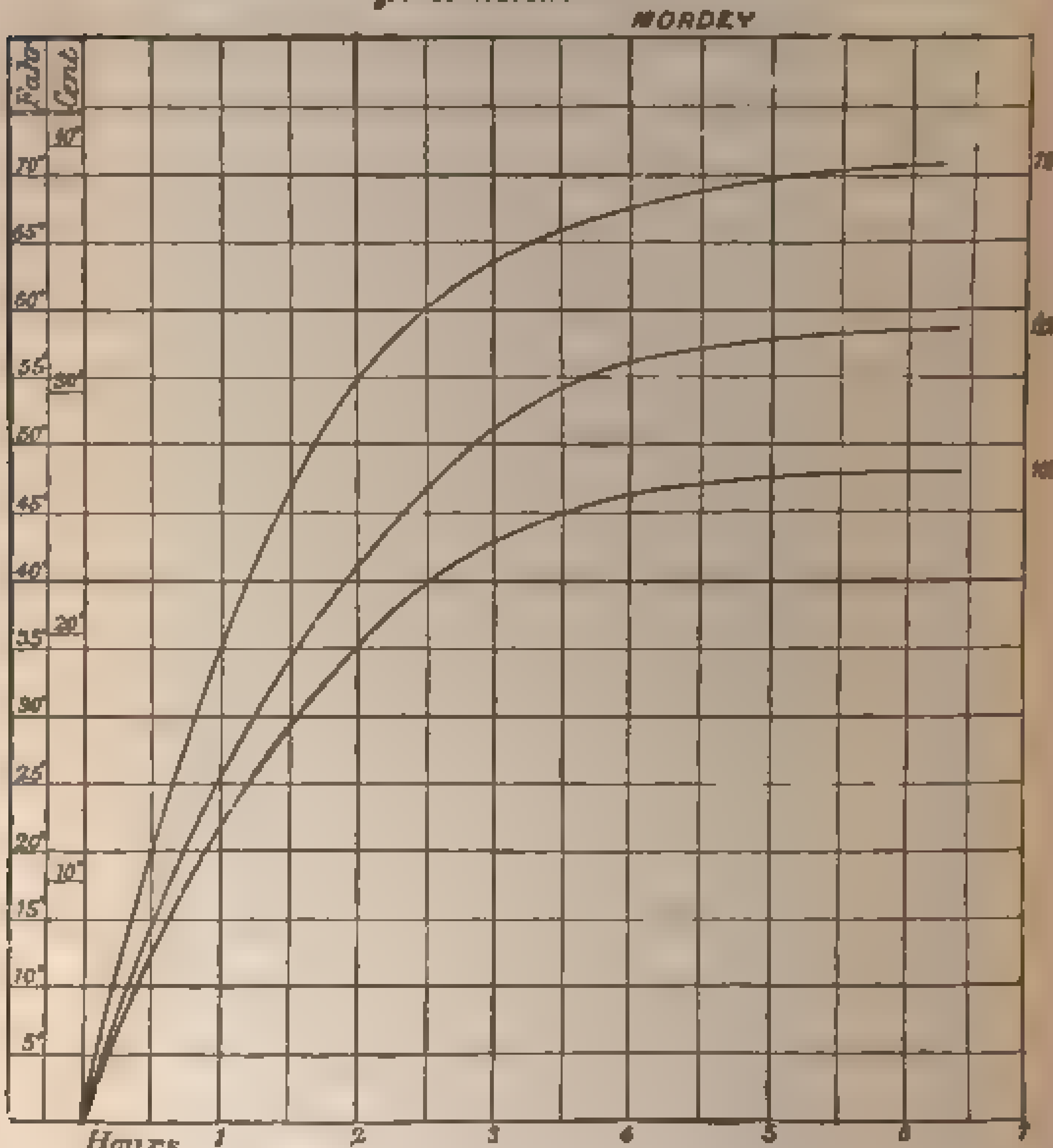
[illegible] a short distance. The [illegible] is then [illegible] ework, made in two pieces and secure[illegible] ons of the co[illegible] not enveloped by the [illegible] ered, mainly for purposes of protection, by [illegible] cast with the frames.

[illegible]mination is of [illegible] not so effective as if [illegible] [illegible]oyed, or as if [illegible] were placed edge on [illegible] the [illegible] the lines [illegible] construction is very easy, [illegible] left [illegible] [illegible] of hoop-iron greatly [illegible] of [illegible]

Mr. Mordey has recently performed a lengthy series of expe[riments] to determine the rate of alternation best suited to his ow[n] transformer, the method adopted being to discover at what r[ate] the least heat was developed in the apparatus. The rise in te[m-]

Fig. 236.

Rise of Temperature of Transformers at various periodicities.



perature was measured by means of a sensitive thermometer, the bulb of which was placed on the iron, and protected from extern[al] influence by a covering of cotton waste. A similar thermomete[r] placed a short distance away, indicated the temperature of th[e] room, which, however, varied but slightly. Each test was co[n-]

[illegible] six and a half hours, the rate [illegible] during that time, while the [illegible] differences, and the [illegible] of a number of [illegible] out.

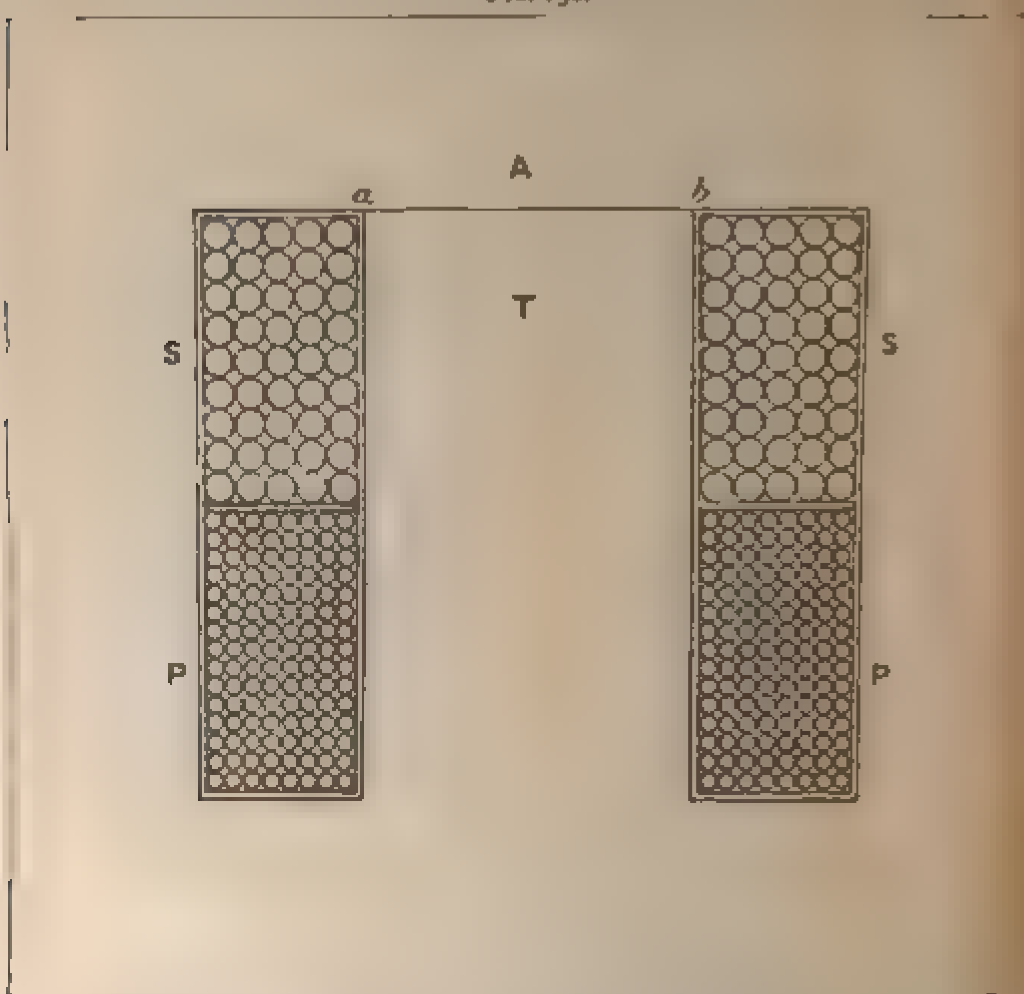
[illegible] readings obtained during [illegible] curves in fig. 236, and the [illegible] lowest curve was that obtained [illegible] alternation per second, the [illegible] ably the greater. This [illegible] was found that the loss was [illegible] alternations per second [illegible] best curve represents the [illegible] with this rate. So that [illegible] there is a best rate for every [illegible] mer, any increase or decrease [illegible] would entail an increased [illegible] by heat. For [illegible] Mr. Mordey has [illegible] ernations per second. There [illegible] little doubt that these [illegible] ly reliable, for it is [illegible] ce in practice that an [illegible] in temperature quickly [illegible] normal rate of alternation [illegible] to be considerably increased [illegible] ced.

[illegible] explanation suggested by [illegible] is probably correct, that at [illegible] above the normal one, the [illegible] principally due to [illegible] for the eddy currents to [illegible] waste more power.

[illegible] is illustrated [illegible] G. S. [illegible]

P P is the primary, and these two coils are wound to the proper shape on a suitable mould or frame, and placed one over the other as indicated in the figure. The strip T of each stamping is divided from the plate at one end, along the line *a b*. In building up the transformer the tongue T thus formed is bent at right angles to the plate, which can then be slipped over the coils, and the tongue bent back into its proper position. A large number of plates being similarly slipped on, the wire is surrounded on all sides by iron.

FIG. 238.



Two strong cast iron plates, and four bolts, hold the plates in position, the plates forming a protective covering to the otherwise exposed ends of the coils. They are also provided with flanges and bolt-holes for fixing the transformer in any required position. The end-plates are frequently fitted with an extra flange as indicated by the dotted lines, to which is screwed a wooden case

a glass front, providing accommodation for a safety fuse, and a double-pole switch, by means of which both wires leading e primary coil can be simultaneously disconnected.

hese transformers are made in a variety of sizes, but the frequent are those capable of transforming down from 2,000 to 100 volts, 2,000 to 50, 1,000 to 100, and 1,000 to 50.

ansformers have been put to a novel and interesting use by Elihu Thomson, who employs them for the purpose of ing the very heavy currents, which are required in his od of electric welding. This method consists in placing the ieces of metal required to be welded end to end, and sub-g them to moderate pressure against each other. A very y current is then passed through them, and as they make fect contact at their opposing surfaces, considerable resist-is there offered to the passage of the current, and a very e heat is consequently developed at the point where it is red to make the weld. If the current is sufficiently strong, pposing surfaces get white hot, and being pressed together unite perfectly, bulging out, however, round the edges. It is sary that the surfaces should be perfectly clean, and a flux, omposition of which depends upon the nature of the metals welded, is usually employed to prevent the oxidation of the ces and so render the weld more perfect. In the case of a little borax is sprinkled over the ends of the rods

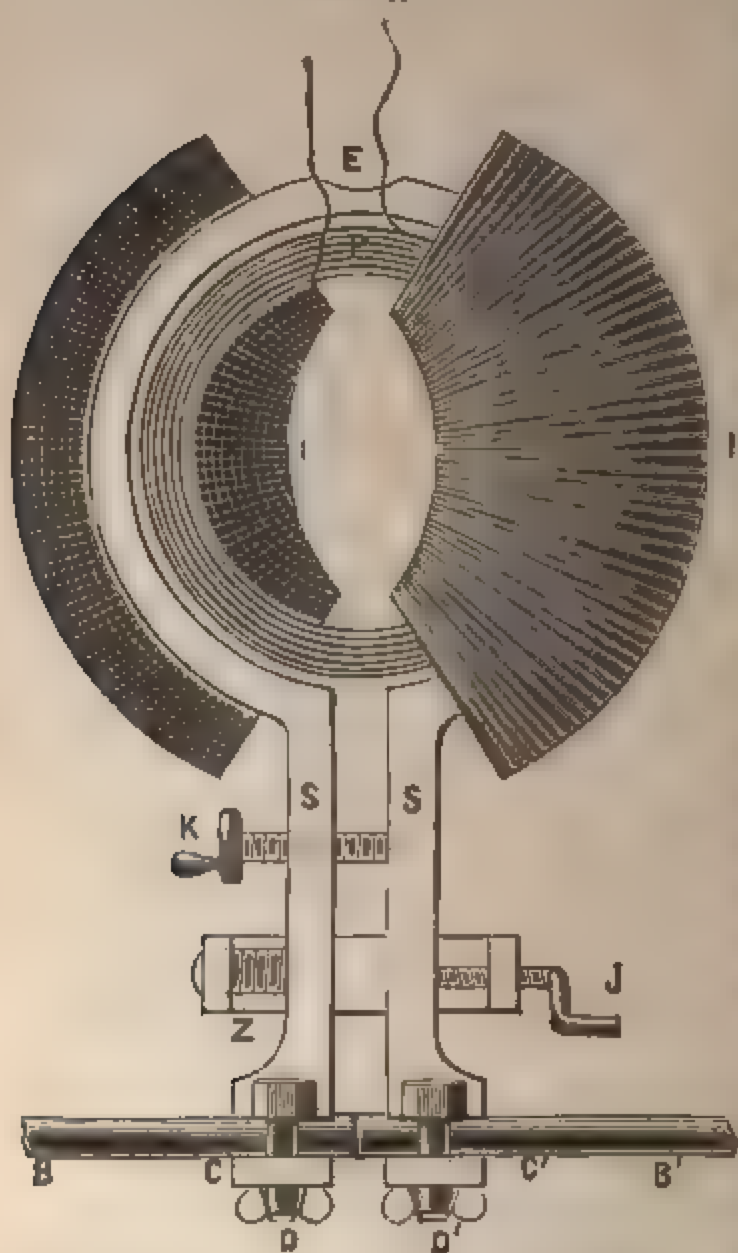
ut in order to sufficiently raise the temperature of thick rods etal, enormous currents are required ; for instance, a current bout 20,000 amperes would be required to weld a steel rod e-eighths of an inch thick. It will readily be understood that ch a case the resistance of the current generator must be mely small, otherwise the power absorbed in it would amount any horse-power.

econdary batteries might be employed for the smaller cur-, but the most economical method is to generate an alter-g current by means of a dynamo, at a fairly high E.M.F., reducing this to a lower E.M.F. by means of a transformer, n at the same time an increase in the current strength.

arious types of transformer have been employed for the pur-one form being illustrated by the diagram in fig. 239. The

primary coil, P, is composed of a number of turns of wi
in a circular coil; the secondary consists of a single
copper strip, S S, bent into a circular form, and placed co
ally with the primary coil. Over the two coils is wound a
of iron wire, I I, in two masses, space being left betw

Fig. 239.



on one side, passage of th leading to mary coil, an other side, out the straight bars the ends of mary coil. T can be held means of th at K, their ties being with massive C C, in wh pieces to be B B′, are fa spiral spring presses the gether, the being regul means of th at J.

For ordina a current of amperes is th mum requir in such a c power is use plied to the primary at an E.M.F. of about 600 volts, the curr twenty amperes. A certain amount of this power is, of cou during the conversion; but a current of 12,000 ampere E.M.F. of nearly one volt can be obtained in the secondary

rtant to observe the reason for most of the heat being the proper point. When the current is started in the rcuit, the resistance at the junction is far greater than e of the whole of the remainder of the circuit ; con- e fall of potential there is comparatively very great, y the whole of the power appearing in the secondary in overcoming the resistance at the opposing surfaces es get hot, and being pressed together, they then make contact. The rise in temperature, however, consider- s the resistance, and consequently the expenditure of is point is still proportionally great. The ease with at can be confined to any particular locality consti- eat advantage of the method. It is usual to quickly welded pieces, and hammer the joint into shape on an lamps make contact with a large surface, to avoid, as far he introduction of resistance, and they are so designed oval of the welded rods can be speedily effected.

meter illustrated in fig. 106 was specially constructed one of these transformers, the potential difference in ry circuit ranging up to about 2·5 volts.

re two distinct methods of distributing power to a ransformers, each of which has several important ad- recommend it. First, the whole of the transformers ned in series, and a constant current sent through f the primary coils Secondly, they may all be con- arallel between two main leads, which are kept at a tential difference, so that the difference of potential ends of all the primary coils is always the same.

ner is in some cases the more economical as regards ctors, for the maximum current in them is only equal plied to one transformer, and is the same when the nount of work is being done as it is during any smaller ut a generator is required which will supply a constant current, under all variations in the external circuit ; h a machine does not at present exist, it becomes employ somewhat unsatisfactory hand regulating de- iculties also arise with regard to the regulation in the ircuit.

The E.M.F. appearing in the secondary circuit varies [illegible] with the strength of the primary current. It also depends upon the number of convolutions in the two coils, and the goodness of the magnetic circuit (that is, upon the mutual induction between the two coils), and also upon the rate of alternation. But as these quantities are usually fixed for any given transformer, we may say that the secondary E.M.F. varies simply with the current sent through the primary. The strength of the secondary current, however, will depend largely upon the resistance of the secondary circuit. Now in the case of a series transformer the primary current is kept constant, therefore the secondary E.M.F. is also constant, and manifestly we cannot maintain a constant potential difference at the secondary terminals, nor a constant secondary current, if the secondary resistance is in any way varied. With the lamps joined up in parallel it would be necessary on [illegible] any one of them out to substitute an equal resistance, which would of course be wasteful.

The mutual induction might be, and in fact has been, varied to suit altering conditions by providing an adjustable core, but this is also unsatisfactory.

A better plan is to join either arc or low resistance incandescent lamps in series, and on removing one to replace it by a [illegible] coil, or, preferably, by a choking coil, that is to say, by a [illegible] wire provided with an iron core, and having considerable self-induction. Its apparent resistance should be equal to that of the lamp which it replaces.

In such a series transformer the number of turns in the secondary is, as a rule, equal to that in the primary, through which a current of 10 amperes is maintained.

But if the transformers are joined up in parallel, and a constant (alternating) potential difference is maintained between the mains across which their primary coils are connected, then an almost constant potential difference can be obtained in the secondary circuit, even though the resistance therein be considerably varied. The lamps can be joined in parallel, and if the transformer is properly designed it will be almost self regulating: for the current passing through the primary, and therefore also the secondary E.M.F., will be almost proportional to the number of lamps through

circuit, that is, inversely proportional to the secondary resist-ce.

The reactions which cause this self regulation are very important d interesting, and in order to better understand them the dent may, with advantage, again read some of the remarks ncerning self induction, &c., in Chapter VII.

On considering the construction of either of the parallel trans-mers just described, it will be apparent that since the primary il consists of many convolutions, and is almost completely sur-unded by a mass of soft iron, the conditions for enormous self-duction exist. In fact, supposing the secondary circuit for the oment to be absent, or disconnected, the self-induction is so great at an appreciable interval of time elapses, before a current in the imary rises to its full value, although the potential difference ay be high. And if the potential difference be rapidly alternated, will not remain constant in one direction long enough to allow y sensible current to be forced through the coil. But supposing e secondary circuit is completed through a rather low resistance, that it is possible for fairly strong currents to flow therein, then e conditions are altered. For directly a current *commences* to w in the primary coil, the lines of force springing out from the re, not only cut the neighbouring convolutions of that coil nding to give the effect known as self-induction, but also cut, d set up an opposite current in the secondary. The lines of rce due to this secondary current re act on the primary coil ee fig. 116) in just the opposite sense to its own lines of force, nding thereby to neutralise the self-inductive effect, and allowing e primary current to rise rapidly. Although the length of the condary is less than that of the primary, the current flowing rough it is much greater, which may be expressed by saying that e lines of force per unit of length are more numerous. Conse-ently, if the secondary resistance is very low, allowing strong rrents to flow, this reaction is competent to reduce the apparent imary self-induction to a very small value.

If then a number of lamps are joined in parallel in the condary circuit, an increase in the number switched in means an crease in the secondary current, and a corresponding increase in e reaction on the primary, which allows a greater current strength

to be attained therein. While when all the lamps are out primary self induction is sufficient to throttle or choke the current almost entirely. On account of these self regulating properties, nearly all distribution is performed by of transformers joined in parallel. Although the size of the is somewhat larger than on the other system, the advan more than counterbalance this objection, and it is a comp easy matter to obtain an alternating generator which co tain a constant potential.

By regarding the action of the primary upon the se coil in the manner developed in Chapter VII., it will be apparent that the currents in the two coils are always in phase; in fact, in an ordinary transformer, the secondary maximum occurs almost simultaneously with the primary maximum and *vice versâ*.

In all cases great care must be taken to avoid a leak the primary to the secondary circuit, for a potential diffe several thousand volts, such as is frequently employed cause a fatal accident in the actual lamp circuit should an point in the primary circuit be making earth at the sam Many safety devices have been suggested, one being th position of an earth connected metal sheathing between coils; so that any breakdown in the insulation would sufficiently strong current to flow to earth, to melt a safety the primary, and thus disconnect that particular transform out interfering with others working in parallel with it.

Such a fuse would also act if by any means the appa short circuited; and something of the kind is essential, for wise not only would all the transformers be deprived of po the heavy current which would result might cause serious

The metal sheathing referred to should be insulated treme care, and must not form a closed metallic circuit ro inner coil, otherwise powerful eddy currents would be indu

Another safety device is due to Major Cardew. Betw horizontal stout brass plates is placed a strip of alumin one end of which is free while the other is attached to th brass plate, which is in its turn connected to earth. Th plate is connected to the secondary coil, so that sho

e assume a much higher potential than the earth, the foil ld be raised by electrostatic attraction, and, touching the upper e, would short-circuit the secondary coil. This would allow fficiently strong current to pass through the primary to melt a e placed in the circuit, and in that way cut out the transformer. he primary circuit is making earth at any point, and any leak- occurs between the primary and the secondary, the upper s plate is immediately raised to a sufficiently high potential attract the foil, and cut out the transformer in the manner cribed.

CHAPTER XIV.

SECONDARY BATTERIES.

It was stated when describing the simple cell, that its great drawback, so far as concerned its general utility, was its comparatively rapid polarisation, a phenomenon which consisted in, or rather resulted from, the development of a film of hydrogen gas upon the surface of the negative plate. This hydrogen being electro-positive to zinc, having, that is to say, a higher potential than zinc, a counter electro-motive force was set up, and the conditions for the flow of a counter current thereby determined. But chemical reactions, similar to those which take place inside a battery cell, may be repeated in any part of the circuit by causing the current to pass through suitably arranged metals and liquids. The usual method of performing electro-chemical experiments is to place the ends of the wires connected to the poles of the battery in a vessel containing the liquid upon which the current is to act. Thus if the ends of two copper wires terminating in copper plates, are connected to the copper and zinc poles respectively of the battery, and placed in a vessel containing acidulated water, then the passage of a current will cause a quantity of that water to be decomposed, and the constituent gases, oxygen and hydrogen, to be released from their state of combination. The hydrogen will accumulate on the surface of the plate connected with the zinc pole, while the oxygen will combine with the other plate, just as it happened with the zinc plate in the simple cell. If, however, we substitute a strip of platinum for the copper plate connected with the copper pole of the battery, the liberated oxygen will not enter into any combination, but remain in a gaseous state, a large portion of it rising into the air, and the remainder adhering to the surface of the platinum or entering its pores and becoming in a measure occluded or absorbed

e absence of chemical combination between the platinum
en is due to the weak chemical affinity subsisting between
simple bodies. By observing proper precautions the two
y be collected separately, the apparatus for the purpose
cing the decomposition and collecting the products being
voltameter. Fig. 240 is an illustration of a serviceable
this class of instrument. There
glass tubes, all in communication
lower extremities, the middle one,
taller than the others and termi-
t the top in a small reservoir, to
two outer tubes, B C, supplied with
and to prevent the liquid over-
when driven from B and C. Plati-
es are fused through the glass and
e inside in strips of platinum foil,
ter extremities being connected
inals fixed on the wooden base.
e ground into the upper portions
bes B, C, affording facilities for the
when required, of the confined
On sending a current through the
the decomposition of the water
ce, the oxygen collecting in one
the hydrogen in the other, ac-
o the direction of the current. The graduations on the
ow readily that the quantity of hydrogen evolved is always
t of the oxygen, in consequence of the fact that the
hat proportion when combined to form water.

platinum electrodes are now disconnected from
ed up to a galvanometer, it will be seen tha
icity is produced by the voltameter, but th
ounter or secondary current is oppo
e primary current which caused th

A series of four voltameters constr
n as Grove's gas battery, is shown
ts of two tubes, A B, closed at the
sel, M. A platinum wire is fused

Fig. 240.

e difference of potential or electro-motive force between the e hydrogen and oxygen is 1·47 volts, and that is a measure of e force of chemical combination between these gases, whence follows that, in order to overcome this force of combination, d therefore to decompose the water, we must employ for each condary cell a primary current whose electro-motive force exceeds 47 volts.

Cells in which the energy of chemical change can be thus ored up, to be given out again when required in the form of an ectric current, are frequently called electrical accumulators or ectrical storage cells. It is not, however, electricity which is ored or accumulated, but rather a quantity of the active constituents of a cell, and it is the subsequent chemical action between these constituents which causes the flow of electricity. It therefore preferable to style them secondary cells. This will e more apparent when it is remembered that a primary cell can ave a current sent through it in the opposite direction to that in hich the current generated by it would flow, and this current will ause the usual negative plate to be more or less dissolved and the ositive plate replenished, setting up the conditions necessary to e re-establishment of a primary current. If, for example, we uppose a powerful reverse current to be urged through a Daniell ell in which the copper sulphate has been exhausted, the copper late will be partially dissolved and copper sulphate reformed, while nc will be deposited upon what remains of the zinc plate. The ell is then able to again generate a current of its own.

Although the water cell is exceedingly interesting, as a secondary generator it is not a practical piece of apparatus, for it is only ble to maintain a current for a very short space of time.

Many experiments have therefore been performed to determine e best liquid and electrodes (the metal plates immersed in the quid), for a practical form of secondary battery. The most siduous worker in this field was Planté, and the result of his bours was the discovery that lead electrodes in a solution of lphuric acid give the best results. He found that a large ortion of the oxygen combined with the plate at which it was leased, *forming an insoluble* compound, which when opposed to *clean metallic lead* plate developed a potential difference of from

2 to 2·5 volts. In Planté's method the lead plates employed were comparatively very large with a view to increasing the amount of active material and reducing as far as possible the resistance of the cell. They were first laid one over the other, but separated by strips of non-conducting material, and then rolled up together in a kind of double spiral. In this way an enormous surface was presented to the liquid. On sending a primary battery current through the cell, from plate to plate, the water was decomposed, the oxygen combining with the metal at the positive electrode to form peroxide of lead, PbO_2, while the hydrogen was precipitated upon the negative electrode in the gaseous form, without in any way attacking the metal. The cell so acted upon became a secondary cell in which the negative electrode acted as the positive plate, being a sheet of lead with a more or less complete film of gaseous hydrogen, the other plate or positive electrode with its film of insoluble lead peroxide behaving as the negative plate. It will thus be seen that the pole of the secondary which is connected to the positive pole of the primary generator, whether a battery or a dynamo machine, becomes the positive pole of the secondary, the other extremity becoming perforce the negative pole.

On permitting the reverse or secondary current to flow, what remained of the hydrogen was oxidised and converted into water, some of the subjacent lead being also oxidised at the expense of the water. On the other hand, the peroxide on the other plate was deoxidised or reduced to metallic lead in a 'spongy' form. These experiments can be very easily performed by sending for a short time a current from three or four good-sized Daniell cells through a vessel containing two pieces of sheet lead immersed in sulphuric acid solution. The piece connected to the copper pole of the battery will, after the passage of the current, be discoloured, and assume a brownish tint, owing to the partial oxidation of the surface of the metal. The amount of chemical change taking place during these reactions is, however, very small, too small to answer any practical purpose, and this is due in a great measure to the comparatively small amount of surface exposed, and to the fact that the greater part of the hydrogen escapes instead of adhering to the plate.

next step taken by Planté in the development of the form of secondary cell was an important one, and that doption of a method for increasing the available surface etal electrodes. It was found that after sending the urrent through the secondary cell for some time, and so vering the surface of the positive electrode with a film of ide, the oxygen released from the water, instead of com- th the lead, formed into bubbles and escaped into the air. s thus for a given metallic surface a limit to the amount le that could be formed.

urrent was consequently reversed, that is to say, the cell red to discharge itself almost completely, so that the ad plate became oxidised, and the other deoxidised and n its turn to the condition of spongy lead, with a propor- creased surface. A fresh direct or charging current on nt through the cell again oxidised this extended lead ad reduced once more the negative surface to the spongy . These reversing operations being continued for some h positive and negative surfaces were eventually very bly increased and rendered more or less porous, one of g always in a state of oxidation. After a few days, how- eriod of rest was allowed between the reversals with a le and most useful effect due to local action. The lead did not form a continuous impervious coating over the allowed the solution to pass between its particles and o contact with the metallic lead. The peroxide being at direct contact with the lead, a simple voltaic pair was blished with the lead for the positive and peroxide for the elements. The acid attacked the lead and formed lead ($PbSO_4$), which is, however, but a poor conductor of elec- is sulphate became available for the subsequent electrolytic he amount of lead actually affected or made active was thus bly increased and the porosity of the plate gradually made l more complete. The process of 'forming' the plates ve been continued until the whole became porous by its n into spongy lead, but there is a practical limit to the r if pursued too far, the plate would fall to pieces simply nt of its inability to mechanically support itself.

The cell being once formed, no further reversal takes place excepting for the purpose of discharging it to perform useful work.

This method of forming the plate is, however, very tedious and very expensive, and many efforts have been made to overcome the objection. One method is to subject the lead to a nitro-sulphuric acid solution which rapidly eats into the metal and increases its surface correspondingly. Another method is to fill a vessel with molten lead, and, as it is on the point of solidification, to make an opening in the bottom, and allow such of the metal as remains in the liquid state to flow out, leaving behind it a spongy porous mass. This is cut up into plates of the required dimensions.

Lead plates pure and simple, often known as Plante plates, are now only occasionally used, the cell more generally employed being that based upon the idea of Faure, which was to coat the plates with a paste of lead oxide, and so to more easily extend the lead surface. A mixture of sulphuric acid and minium or red lead (Pb_3O_4) was made, which resulted in the formation of lead sulphate ($PbSO_4$). This was applied to both the positive and negative plates, that on the plate in connection with the positive pole of the primary battery being by the current converted into peroxide of lead, by the absorption of oxygen, while the paste on the other plate was reduced more or less to the condition of spongy lead. It will thus be seen that the great value of Faure's invention is to minimise the amount of energy required to be expended in 'forming' the plates.

It is now the practice to use a paste of litharge (PbO) and acid for the plate connected to the negative pole, although makers vary the pastes considerably. In some cases minium only is employed. In others a mixture of litharge and lead sulphate; and in others, again, all three substances, viz. minium, litharge, and lead sulphate enter into the constitution of the paste. In all cases, however, the ultimate result of the initial charging current is the same, viz. the conversion of the paste on the positive plate into peroxide, and of the paste on the negative plate into spongy lead. Assuming the plates to be in the state of lead sulphate

ad monoxide (or litharge) respectively, the initial action may mmarised by the equation :-

$$SO_4 + 2OH_2 + PbO = PbO_2 + SO_4H_2 + OH_2 + Pb$$

ad phate.	Water.	Lead monoxide.	Lead peroxide.	Sulphuric acid.	Water.	Lead.

will be seen in this case that the positive plate exchanges $)_4$ for two atoms of oxygen, that the negative plate loses its o, and that one of the water molecules is converted into uric acid, so that the quantity of acid in the solution gradually ses, while the quantity of water as steadily diminishes.

he secondary current, during the process of discharge, reverses state of affairs, the two plates being converted into lead ate. The process is doubtless brought about in several s, but they may be represented by the following equations :—

$$O_2 + 2SO_4H_2 + Pb = PbO + SO_4H_2 + OH_2 + PbSO_4.$$

he lead monoxide then reacts with the sulphuric acid and lead sulphate and water thus :—

$$PbO + SO_4H_2 = PbSO_4 + OH_2.$$

r combining the two equations :—

$$PbO_2 + 2SO_4H_2 + Pb = 2PbSO_4 + 2OH_2.$$

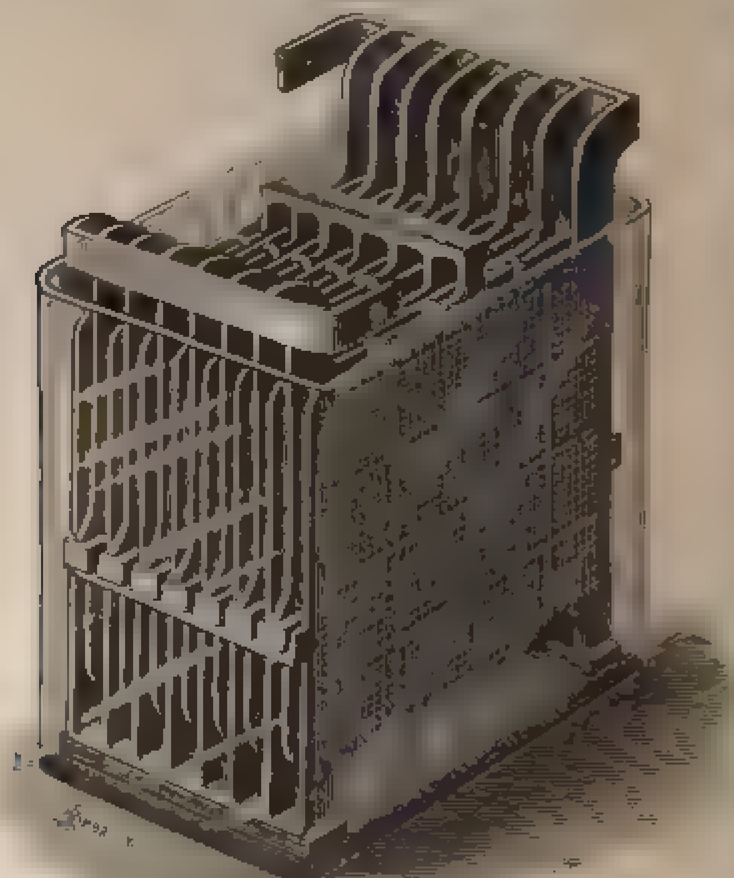
hese reactions, however, affect only a small portion of the); that is to say, the active portion of the cell is far less than which remains passive.

he pastes, one and all, adhere very feebly to the lead and many devices have been attempted to secure better sion. One of the earliest plans was to score or scratch ead surface. Then it was indented, the indentations deve- g subsequently into perforations The paste, on being sed into the holes, certainly kept its position much better when simply smeared over the surface of the lead, but the tity of paste exposed to the liquid was reduced Even- leaden grids were cast containing sufficient metal to bear eight of the plate, the holes being square and somewhat idal, that is, smaller in the middle of the plate than on the es, so as to prevent, as far as possible, the peroxide from

falling out. An illustration of the latest type of cell, m… tured by the Electrical Power Storage Co., is given in f… A number of grids of lead, or of a hard lead alloy (lead … with a small proportion of antimony), are filled with the … the number varying with the size of the cell, but always w… negative plate in excess of the number of positive plates.

The cells are usually provided with 15 or 23 plates, of … 7 and 11 respectively are intended for the positive, a…

Fig. 243.



remainder for the negative surface. The object of having … number of plates, is, of course, to increase the capacity of th… and to reduce its internal resistance without resorting to t… of inconveniently large plates. Each grid measures about 8… inches, and is $\frac{3}{16}$ inch thick, the weight being about 5 lbs.

The lead grids are provided with lugs for the purpose of … nection, the lugs of the positive plates being all melted … on to one leaden strip or band, the lugs of the negative plate… similarly secured to another strip. The plates are placed …

alternately, the distance between two adjacent plates being out a quarter of an inch, which is sufficient to allow pieces of plates or paste that may become detached to fall to the bottom the cell. Bent strips or forks of ebonite, celluloid, or other itable material are placed between the plates to keep them apart d prevent internal contact. The negative plates in each cell are o held rigidly together by means of two stout strips of lead elted on to solid extensions from the lower edges, two others eing also secured to the sides of the plates about half-way up. hese connecting strips, one of which is shown at the left-hand de of the figure, serve as a further means of keeping the negative ates in position. The bottom strips rest on slabs or strips of raffined or varnished wood so as to support them at a height of out 1½ inch above the bottom of the containing cell, affording ereby plenty of room for any scales or pellets that may fall to e bottom to be clear of the plates. Lugs cast on to the sides the positive plates rest in small ebonite shoes, which are supported by the side strips of lead attached to the negative plates. he positives are also connected together across the top by the bstantial lead strip shown a little to the right of the middle of e upper edges of the plates. The connecting strip to be seen the left is melted on to projections from the corners of the ates, consequently they can be readily lifted out of the cell, without necessitating the removal of the negative plates. The containing vessels are best made of stout glass, an opportunity being us afforded for the proper inspection of the cell without taking to pieces or removing the plates. The upper portion of the ter surface of the glass vessel should be coated with wax, vaseine, or some such material, to prevent 'creeping' and escape of e current by way of the moisture that would otherwise condense er the whole of the external surface. To further ensure good insulation, the cell should be placed on a varnished wooden tray or on o triangular pieces of wood supported by insulators of the so-called ushroom pattern illustrated in fig. 243. A sectional view of the sulator is also given in fig. 244. The channel in the lower cup ntains a quantity of resin oil or of some other non evaporating , in which the upper cup, coated with shellac varnish, rests. metimes, however, the cells are simply supported on shelving made

of three or four strips of triangular wood. The cells should not be quite in contact, but tolerably close together, and the connections made by clamping the lead strips of adjacent cells firmly together the positive pole of one cell to the negative of the

Fig. 243.

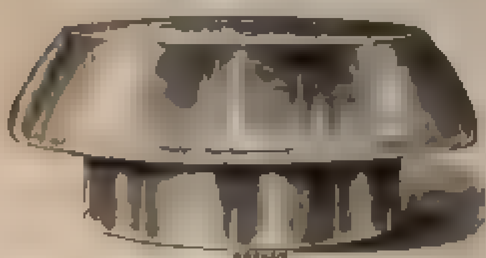
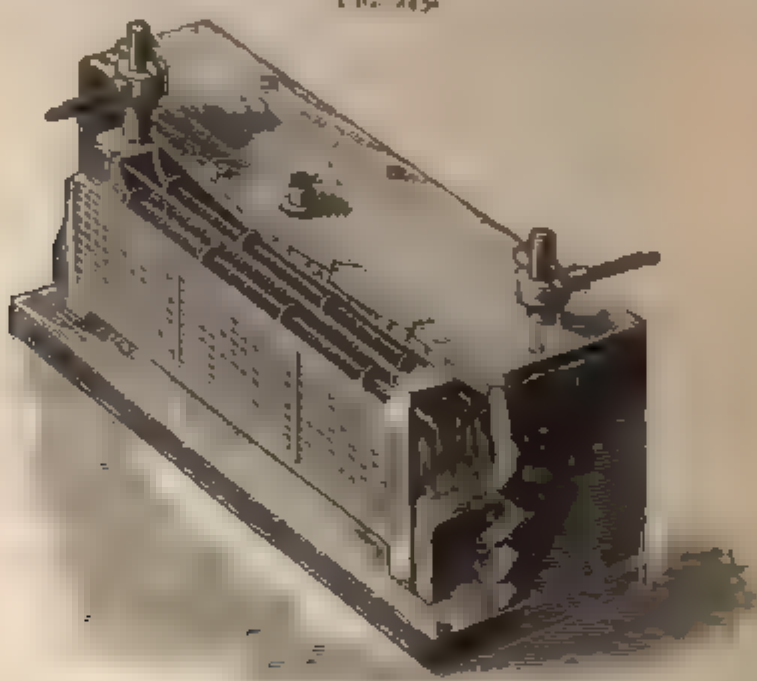


Fig. 244.

next, and so on. The positive poles should be painted red for the purpose of distinction. All leading wires should be as short and of as low resistance as possible, so as to avoid unnecessary waste of energy in overcoming the resistance of the connections.

Fig. 245 illustrates a very useful form of cell specially con-

Fig. 245.



structed for train lighting. It is enclosed, like other classes of cells intended for ship lighting, carriage lighting, &c., in a teak box, and contains, to suit different requirements, either nine or fifteen plates separated by celluloid forks. Sometimes, in order to further avoid the risk of contact and short circuiting between adjacent

, thin perforated celluloid sheets are interposed between Connection between adjacent cells is of course made ex-ly, rods attached to the connecting strips passing through vers for the purpose. Connecting rings fit on to these rods, gh slots in which wedges are driven to secure good electrical ct, the rings being joined together by stout wires or rods, licated in the figure. Cells are also made specially for tram-iving, these being constructed as light as they practically can ed enclosed in teak or ebonite boxes. They are made in lifferent sizes containing as many different numbers of plates. few details concerning some of these various types of cells oubtless prove of service. In the subjoined table, L indicates ntended for general, C for railway carriage, and T for tramcar ng.

scription of Cell		Acid 1·170 sp. g. for each Cell	Working Rate		Capacity	Approximate External Dimensions				Weight of Cell complete with acid
f	Material of Box		Charge Amperes	Discharge Amperes	Ampere-Hours	Length	Width	Height	Height over all	
		lbs.				ins.	ins.	ins.	ins.	lbs.
	Teak	35	25 to 30	1 to 30	330	9½	13	17½	19½	143
	Glass	47	25 „ 30	1 „ 30	330	9¾	11¼	13¼	15¾	128
	Teak	53	38 „ 46	1 „ 40	500	14¾	13	17½	19½	228
	Glass	67	38 „ 46	1 „ 40	500	14	11¼	13¾	15½	211
	Teak	8·4	6 „ 8	1 „ 8	72	6	13½	6¼	7½	38
	Teak	14	12 „ 14	1 „ 14	130	9½	14½	6¼	7½	62
	Teak	14	24 „ 28	1 „ 30	95	8¼	8¼	11⅛	13⅜	53
	Ebonite	14	24 „ 28	1 „ 30	95	8	7¼	11	12¼	42
	Teak	22	38 „ 42	1 „ 50	1[illegible]5	13¼	8¾	11¼	13⅜	80
	Ebonite	22	38 „ 42	1 „ 50	145	12¼	7¾	11	12¼	66

lessrs. Elwell Parker also manufacture a very useful form of dary cell, the main principles of which, however, are similar ose involved in the construction of the cell just described. of these cells are shown in fig. 246. The distinguishing res consist in the construction of the grids, and the method pporting the plates. The grids are made of an alloy which d to be considerably stronger than the material formerly oyed, and to be practically inoxidisable in the sulphuric acid on. The holes in the grids are 'burred' over, by a process

patented by Messrs. Drake and Gorham, so as to form 'lips' which assist in keeping the pellets of oxide in their places. The plates are ingeniously supported and kept in position by means of round projections which fit into parallel rows of holes perforated in slabs of ebonite, as shown in the figure. This is a detail, but it is a feature of some importance. In an earlier form of cell, the leaden pins were all in one line, so that should any conducting material fall into the cell it might drop across them and cause short circuiting. To effectually prevent contact between adjacent plates, small ebonite 'forks' are placed between them, and the set of plates is

Fig. 246.

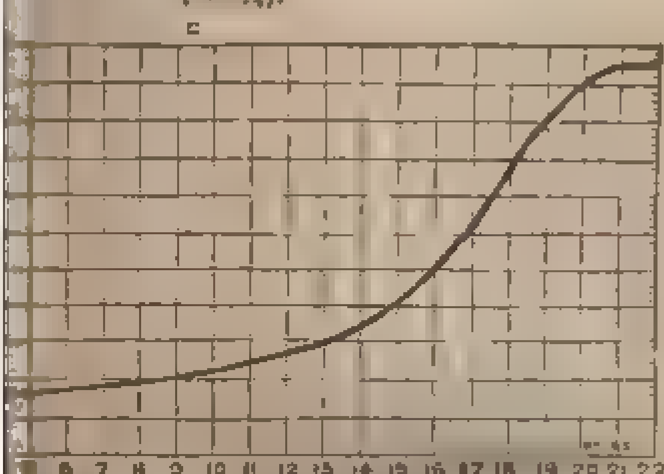
supported on blocks of paraffined wood to keep them clear of the bottom of the cell.

While it is essential that great care should be exercised in the manufacture of secondary cells, the treatment to which they are subjected is also a matter of great importance.

The charging current should be proportional to the number of plates, and, for the size of cell used for lighting purposes, should be equal to about 4 amperes per positive plate, so that the 15-plate cell requires 24 to 30 amperes. When the current exceeds this amount, it cannot increase the reduction of the sulphate of lead in proportion to the extra amount of current, and the surplus current is therefore wasted in the decomposition of water and the premature evolution of bubbles of oxygen gas from the positive surface, a phenomenon which is technically known as boiling. There

the too powerful current will cause [illegible] of ...tes, which being very close [illegible], stand a ...king contact one with the other, and so short-... Precaution has also to be taken that the ...e of the charging current should exceed that of ...charging current by about 10 per cent., or ...ut 2·5 volts per cell, being, however, a little ...han when approaching the completion of the ...ging should be continued until the solution ...pearance, consequent on the evolution of free ...e plates having then absorbed as much of the ...ke up. The E.M.F. of a secondary cell rises ...ormly, with the continuance of the charging ...important experiments, performed by Messrs. ...e with a battery of 15 cells, a current of 22 ...ed, by which the E.M.F. was raised from 2·02 ...t. The variations in the rate of increase are ...m which it will be seen that after 220 ampere-

Fig. 347.



...n, that is to say, after a charging current of ... maintained for a period of 10 hours, the ...ally to 2·13 volts. At [illegible] 14 hours ...E.M.F. was 2·17 volts, a [illegible] sudden rise ... which was [illegible] [illegible] were ...m E.M.F. [illegible] 2·5 volts, ... freely [illegible]. [illegible] many ...[illegible] as boiling. [illegible] years

considered to be very injurious to charge the battery to an E.M.F. exceeding about 2·25 volts per cell, it being thought that charging beyond this point, or overcharging as it was called, was responsible for the remarkable tendency of the plates to buckle or twist out of shape, and so to loosen and detach the pellets. This, it was supposed, was brought about by the freed oxygen destroying the grid. It has, however, been conclusively proved that overcharging is not only harmless, but actually beneficial. In the experiments previously referred to, some cells were charged without cessation in order to ascertain the exact amount of current necessary to destroy the grid. It was soon evident that the process was, at any rate, a slow one; but the experiment was continued, until the full prescribed current had been passed through, for more than two months. At the end of that time it was found that the lead conductor was practically as sound as before charging. The coating of fine peroxide formed on the surface was very thin; there was no sign whatever of buckling, and, further, the specific gravity of the solution, when the cells were left in their then fully charged condition, remained absolutely unaltered. The conclusion thence drawn was that the oxidisation of the grid caused by charging only penetrated to a very limited depth, and then ceased entirely, and that the coating of fine peroxide formed, actually protected the grid not only from deterioration by overcharging, but also from local action, hitherto supposed to be unavoidable. It was, then, established that the life of the grids was not proportional to the amount of charging, *i.e.*, to the number of ampere-hours put into a cell. We shall return to this question presently, but it is necessary now to enlarge upon the precautions to be adopted in the process of charging.

The solution, prior to charging, should be put in the cells to the height of about ½ an inch above the negative plates. It should contain about 20 per cent. of pure sulphuric acid, and have a specific gravity of 1·170 (that is, if a given volume of water weighs say 1 pound, the weight of an equal volume of the solution should be 1·170 pounds); but it will be seen from the equations already given that some of the water in the cell is changed to sulphuric acid, and causes the proportion of the latter to rise to about 33 per cent., increasing the specific gravity to about 1·220. The

f sulphuric acid, which is, however, lost on recharging ses the conductivity of the liquid about 10 per cent. rument for measuring the specific gravity of the acid comes, therefore, a necessity. Such a piece of apparatus ıydrometer, or, for this special dometer, a useful form being in fig. 248, which is simply a weighted at the bottom with a small shot. The lower the vity of the solution, that is to ater it becomes bulk for bulk, will the hydrometer be im- the liquid increases in density ent becomes relatively lighter re rises. Consequently, the tube can be made to indicate density corresponding with the ths to which the tube descends. y useful form is that known as tometer (fig. 249), which con- lattened glass tube with the bent over so as to allow it to edge of the glass containing- tube being also perforated to e free circulation of the solu- le the tube are four small glass ntaining liquids of different vities and different colours; e rises or falls at a distinct vity, and allows thereby the relative density of the solu- ery readily observed.

Fig. 248.

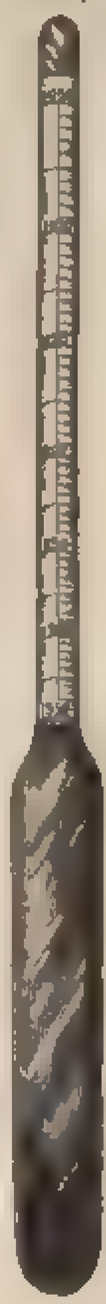


Fig. 249.

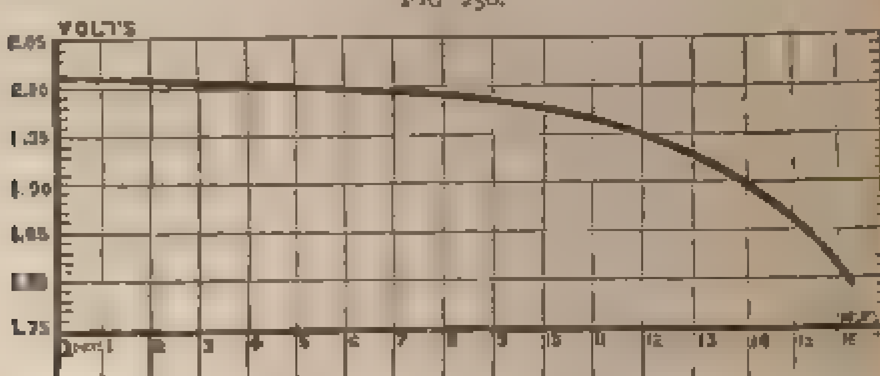
the discharge the density of falls until, when the cell is exhausted, it is only 1·150. The relative density of thus affords an excellent means of ascertaining the the cell.

our of the plates affords another good indication of

their quality, the peroxidised positive plate being of a brownish or deep-reddish hue, and the negative or spongy lead plate being coloured grey or slate tint. There is thus a marked distinction in the colouration, which should always be discernible.

During the discharge the E.M.F. of the cells speedily falls to about two volts each, the higher initial electro motive force being, no doubt, mainly due to the presence of hydrogen on the spongy lead plate. When this has been oxidised there remains the lead surface between which and the peroxide plate the electromotive force falls very slowly to about 1·98 volt. The fall is then slightly faster, although after an output of 400 ampere hours at the rate of 25 amperes, the total drop from the time that the cell settles down to steady work at 2·02 volts, is only about ten per cent. The rate at which the fall of E.M.F. takes place is clearly shown in the instructive curve given in fig. 250, determined experimentally by

FIG. 250.



Messrs. Drake and Gorham. The discharge was continued, however, until the E.M.F. was only 1·80 volt per cell, which is a point about 0·1 lower than it is practically advisable to go. With a fall to 1·90 volt the difference is only about 5 per cent.

In an experiment performed to ascertain the effect upon the plates of a rapid discharge a battery was divided into two halves, one of which (A) was repeatedly run out, but the other (B) was never discharged beyond the point at which the E.M.F. commenced to drop. The experiment extended over a considerable time, but gave the instructive result that when exactly the same number of ampere-hours had been taken out of each half, the plates of (A) showed signs of expansion or growing, whereas in those of (B) no change could be detected. The life of the grid was

therefore proved to be dependent not on the *amount* of ampere-hours taken out, or on the work done, but on the treatment of the plates.

By the time the E.M.F. has dropped to 1·90 volt the greater portion of the surfaces will have resumed the condition of lead sulphate ($PbSO_4$), and there will then be considerable risk of the formation of a more obdurate form of sulphate, Pb_2SO_5, caused probably by the $PbSO_4$ combining with the monoxide. This hard white sulphate is very troublesome. It is insoluble, non-conducting, and very adhesive. When it falls off the plate it generally carries with it some of the active material, which is therefore wasted. It is consequently highly important that the E.M.F. of the cells should be tested periodically with a special low-reading voltmeter. Two or three of these instruments were described in Chapter VI.

The experiments further showed that buckling was almost invariably accompanied by the formation of the hard sulphate on the face of the plates, and that this enamelling could be prevented by charging, and was not due to impurities in the oxides or acid used; further, that when the plates were free from sulphate there was no tendency to buckle. In the case of the first use of cells, when the acid was first put in, the specific gravity dropped in spite of the charging, indicating the formation of sulphate; by persevering in charging the sulphate disappeared, and with it the tendency to buckle. It is, therefore, evident, as already stated, that in order to avoid buckling of the peroxide plates, cells on their first use (whether new or after long disuse) should be charged incessantly until they are considerably overcharged.

It has been ascertained that in almost every case where abnormal disintegration takes place the plugs of active material fall out of the plates in complete halves and in very hard condition; and analysis has shown that they contain an excess of sulphate, due to insufficient charging. On the other hand, in a few instances the active material has been found to have become disintegrated and fallen off in a fine powder, and this was specially observable when on account of a leak in the containing-vessel and consequent frequent addition of water, the solution had become extremely weak,

In this case practically no sulphate was present, and the mass simply lost cohesiveness.

It would seem, then, that a certain proportion of sulphate in the material is necessary to bind together, but that excess must be avoided.

Buckling appears to be due to the expansion of the paste during sulphating, for lead, being a very ductile but non-elastic body, does not re-assume its proper shape when the subsequent partial contraction of the paste takes place, and to this must also be attributed the loosening of the pellets. The contraction being but partial, the positive plates become gradually increased in size with continued use.

The electrolytic effect of the oxygen upon the lead grid, slow as it is, is to render it more or less brittle, whence the bars crack and split, and the plate is then practically worn out. Owing to the stretching effect of the paste, it is necessary that the grid should be of equal strength throughout, and not made stronger in one direction than in another.

Mr. Reckenzaun has found that a positive plate which had when new a surface of 90 square inches, grew to 94·76 inches after one year's daily use, while others showed when almost worn out an increase from 90 to 97 square inches; these measurements being simply the product of the length into the breadth of the plate, and independent of corroded or oxidised furrows. The actual amount of surface in contact with the liquid is considerably greater than these figures would indicate, owing to the irregularities produced by the solution. The life of a positive plate is not, however, so brief as might be anticipated from the many little difficulties which beset it, for with fair and continuous usage its period of durability amounts to about three years. The decay of the plate is more rapid in the lower than in the upper half, owing probably to the greater density of the acid solution in that portion of the cell. The life of a negative plate, which is subject to but few of the troubles attending the positive plate, has been estimated at ten years, although it remains for time to demonstrate the truth or otherwise of this calculation.

A 15-plate cell is capable of yielding a current ranging from 1 ampere or less to about 30 amperes, or at the maximum rate of

amperes per positive plate. The discharging current may e even a little higher than the maximum used in charging. It ould not, however, exceed it by more than about 10 per cent., herwise the subsequent efficiency of the cell will, as already own, be seriously imperilled. Of course, the total output cannot ceed or even equal the amount of energy put in.

When the rate of discharge is too great, there is considerable k of causing unequal expansion of the plates, resulting sooner or ter in buckling, loosening of the pellets, and short circuiting. It impossible to prevent a certain amount of the obdurate sulhate forming, and this being an insulator reduces the available tive surface and increases the resistance of the cell. As already dicated, considerable difficulty is experienced in removing this lphate, and under any circumstances a certain amount of distegration of the peroxide is sure to ensue.

But experiments have been performed which tend to show that ith a considerable increase in the charging E.M.F. the sulphate n be decomposed. Its formation can be to some extent prented, by the addition of a small percentage of sodium sulphate (Na_2SO_4).

If the cells are discharged and then left to stand idle for any ngth of time, the sulphating takes place rapidly, and causes preature buckling.

The capacity of a cell may be defined as the amount of energy is capable of storing, and is calculated generally in ampere hours, at is to say, it is the product of the number of amperes at which e cell is able to discharge, into the number of hours through hich it can maintain that discharge. Capacity is also estimated y the ratio between the weight of the material and the electrical tput. Thus the ordinary form of cells yields about four ampereours per pound of plates complete, while, it is said, the best rm of Planté cells only yields about one-half as much. The mount of surface exposed to the solution really determines the arge which a cell can receive, and is therefore a measure of capacity.

The capacity of a cell is an important consideration, seeing at the prime cost is considerable, that the cell is bulky and therere requires correspondingly ample accommodation, and that at

required, while the former frequently receives its charge gradually or even intermittently as opportunity arises, whereas its rate of discharge often approaches the highest possible, and frequently exceeds the charging rate, when, of course, the duration of the discharge is considerably shorter than that of the charge.

No better illustration of the value of secondary cells as a means of storing electrical energy can be afforded than that referred to by Mr. Preece in a lecture before the Society of Arts. He said: 'On March 30 my gas-engine broke down. I quite forgot to give notice to the makers to send down men to repair it until six days had elapsed. It took five more days to repair the engine, so that for eleven days I had not been able to re-charge the cells; but during all these days the light never failed, and we were not in any way inconvenienced. The useful capacity of my cells is 330 ampere-hours, and my nightly consumption is now about 30 ampere-hours. This was a very good test of the efficiency of the cells, for I obtained from them nearly all the energy they could usefully give. Only two cells were really exhausted during this time, but as I had two spare cells to replace them, their exhaustion did not cause me any inconvenience. The E.M.F. fell to 1·8 per cell, and the light in consequence was not so brilliant as usual. A good practical test of the efficiency of a battery like this is better than any isolated tests on single cells.' It will thus be seen that the use of a secondary battery reduces considerably the risk of a total stoppage resulting from the breakdown of the engine or other part of the machinery.

Secondary cells have also the advantage that, where they are used in sufficient numbers to maintain the ordinary number of lamps, they can, on emergency, be used to considerably increase the total amount of current supplied. For example, suppose the dynamo to be able to generate the same amount of current as the secondaries, the latter can be charged during the day, and both dynamo and battery employed independently for lighting purposes in the evening.

The battery is very useful as a regulator for maintaining a constant potential difference on a variable circuit which is being worked by a dynamo machine.

For such work, the battery is joined up across the terminals of

main circuit. When the current exceeds a certain prescribed limit, the soft iron core is attracted, and a horizontal spring attached to it completes a local circuit, causing one of the cells to send a current through an ordinary electric trembling bell

In addition to these, there are many other pieces of apparatus, ingenious in their way, and useful for special purposes, which we need scarcely describe, although some of them will be referred to in the closing chapter

CHAPTER XV.

ARC LAMPS.

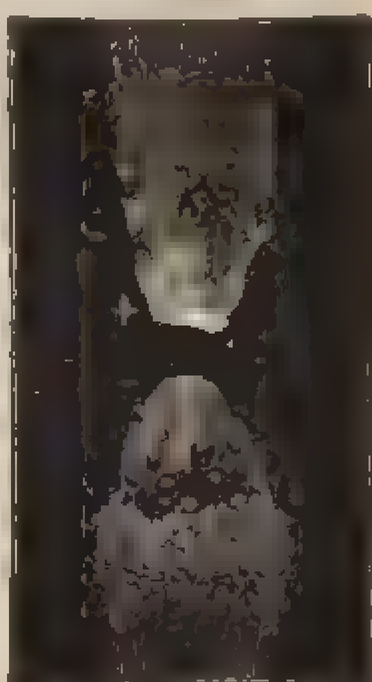
UNTIL within the last few years electric lighting was, except in the laboratory, only performed by the agency of the electric arc, a development of the classical experiment made by Davy in 1810, when he employed 2,000 primary cells of a very crude type, which he connected to two pieces of light wood charcoal about an inch long and one sixth of an inch in diameter. When these 'were brought near each other, (within the thirtieth or fortieth part of an inch), a bright spark was produced, and more than half the volume of the charcoal became ignited to whiteness; and, by withdrawing the points from each other a constant discharge took place through the heated air in a space equal at least to four inches, producing a most brilliant ascending arch of light, broad and conical in form in the middle.' When any substance was introduced into the arc produced by this battery 'it became incandescent: platinum melted like wax in the flame of a candle; sapphire, magnesia, lime, and the most refractory substances were fused. Fragments of diamond and granite rapidly disappeared without undergoing any previous fusion.' The arched form taken by the luminous particles of carbon, resulted from the upward rush of the subjacent heated air. Were the carbons placed vertically, the particles would be disposed more symmetrically, and bear little or no resemblance to an arch. The term arch, in its abbreviated form, arc, is, however, retained as the name of the luminous space between the carbons.

The electric arc can be reproduced by placing in electrical contact two pieces of carbon, either of the gas retort or of the prepared type, these forming the electrodes of a battery of twenty five or more Grove or other cells of a similar E.M.F., and then drawing

the carbons apart for a short distance. The electro-motive force of such a battery is altogether inadequate to cause a spark to dart across even the shortest air space. When, however, these rods are made to touch, a current is initiated, the particles in contact are immediately heated, and on separating the contact-surfaces, molecular disintegration and volatilisation take place and the air space is impregnated with so great a quantity of carbon particles raised by the current to a state of incandescence, that the resistance of the space is so far reduced as to allow the current to be maintained. The initiation of the arc is assisted by the momentary increase in the current due to self induction in the circuit when the carbons are separated. The distance to which the carbons can be separated without absolutely disconnecting the circuit and so causing the arc to be broken, depends upon the E.M.F. of the battery, and can therefore, within certain limits, be increased by increasing the number of cells, or the potential difference at the dynamo terminals.

The maintenance of the ends of the carbon rods in a state of incandescence also involves a certain amount of consumption by ordinary combustion, some of the particles uniting chemically with the constituents of the atmosphere, although the products of combustion are very much smaller in quantity and far less harmful than those derived from a gas, oil, or candle flame. The two rods are not, however, consumed at equal rates, the consumption of the rod connected to the positive pole of the dynamo or battery, and called, therefore, the positive carbon, being approximately twice as much as that of the other or negative carbon; but this must not be taken as being invariably correct. One very interesting and important feature in connection with the electric arc is the difference of formation given to the carbon rods. The end of the positive rod becomes in a short time (see fig. 252) worn down to a somewhat conical form, the apex of the cone being, however, absent,

FIG. 252



blended together. These colours are red, orange, yellow, green, blue, indigo, and violet, and it is by the simultaneous reception of these rays, in certain definite proportions, by the optic nerves, that the sensation of white light is conveyed to the brain. The generally accepted theory which endeavours to explain the manner in which a beam of light is propagated, is based on the assumption that all interstellar space, and likewise the space between the minute particles of all material bodies, is pervaded by that mysterious medium already referred to as ether.

A body may be said to be a luminous substance when it is a source of light-rays, such as the sun or a candle flame. Now the luminosity of a body is ascribed to an almost infinitely rapid vibration of its molecules; this vibratory motion is communicated to the ether particles pervading and enveloping the substance, and is propagated in all directions in the form of spherical wave-motions. The colour of the ray varies with or is determined by the rate of vibration. The velocity with which light travels is about 186,000 miles per second, and it has been calculated that the length of a wave of the extreme red end of the spectrum (that is to say, of a luminous ray having the lowest rate of vibration), is such that 39,000 such waves, placed end to end, would cover only one inch, while 64,631 of the extreme violet waves would be required to span the same distance. It follows that in one second, 464 millions of millions of red waves, and 678 millions of millions of violet waves, enter the eye and strike the optic nerves.

If a beam of solar light (S, fig. 253) is allowed to pass through a hole in the shutter or wall of an otherwise absolutely dark room, it will illuminate a small section of the floor, K, but if a prism or wedge shaped piece of glass (P) is placed in the track of the beam of light, after the manner shown in the diagram, the beam will be diverted and the rays separated; on emerging and being allowed to fall upon the screen, H, or even on the wall of the room, it will be found to consist of the seven colours above enumerated. This many-coloured band of light is generally referred to as the spectrum.

If the beam is not of a pure white colour, the impurity or irregularity may be due to the chemical constitution of the source

of light, or to varying degrees of luminosity. For example, if a beam from a red-hot substance is allowed to fall upon the prism, the decomposition or separation of the rays will not result in the formation of the seven coloured bands, those near the violet end of the spectrum being absent on account of the vibrations being insufficiently rapid to produce them. When a source of light is heated to different degrees of luminosity, the spectra resulting therefrom will consequently vary, while, on the other hand, if it is raised at different times to the same temperature, and therefore to the same degree of luminosity, the spectra obtained will be identically the same in each case. Now it has been ascertained that the spectra of the white light emitted by the incandescent crater of the positive carbon are always identically the same, that in fact the same proportion between the various coloured bands is always evidenced, whence it is at once deduced that the temperature of that portion of the arc is always raised to the same point. This constitutes one great reason for accepting the proposition that the transference of carbon particles from the positive to the negative rod, is caused by a volatilisation at the former and a resolidification at the latter; for, so far as experiment has hitherto led us, there is for a given material, a constant critical point of temperature at which a change from the solid to liquid or to the gaseous state ensues, and, the most important point of all, this temperature is not any further increased until the whole of the solid body has been so changed. It will be evident that the admixture with the carbon of any foreign body (all such bodies having a lower critical point of temperature than carbon), must lower the temperature at which volatilisation

Fig. [illegible]

ensues, and therefore reduce the luminosity of the crater. Moreover, when a body is transformed from the solid to the liquid or gaseous state, a certain amount of heat, known as the latent heat, is absorbed in the process. Thus one pound of ice at the freezing temperature absorbs about as much heat during its conversion into water at the same temperature, as would suffice to raise the same mass of water from the freezing temperature to 80° C., whence the latent heat of water is said to be 80° C. On the other hand, when a liquid is solidified a corresponding amount of heat is given out during the change. Thus one pound of water at the freezing temperature in being converted into ice, gives out as much heat as would raise the temperature of the same mass to 80° C. Returning then to the electric arc, if the positive carbon is more or less volatilised, a certain quantity of heat is absorbed in bringing about the change, whence, on the carbon being resolidified on the negative rod, a corresponding quantity of heat is evolved.

These reactions have been made to account for a very remarkable phenomenon pertaining to the electric arc. It has been found that when the arc is established a back or counter E.M.F. is set up amounting to nearly 39 volts. This effect is somewhat analogous to that accounting for the reaction which is set up when a current is sent through a voltameter, and which was fully entered into in the preceding chapter. The effect is also parallel to that remarkable feature in the action of electric motors, viz., the counter E.M.F. which is set up by the armature when it is caused to revolve in an established electro-magnetic field. In fact, the phenomenon affords a new demonstration of the law that every action brought about by any force, sets up a reaction or counter force.

The theory of the existence of this counter E.M.F. does not, however, depend solely upon the assumed volatilisation and resolidification of the carbon particles. It is a matter of general knowledge, and one which has given rise to many different conjectures, that the *apparent* resistance of the arc does not increase proportionally with the distance between the rods. The resistance of an arc of one-tenth of an inch appears, in fact, to be nothing like double that of an arc of one-twentieth of an inch. If both

he resistance of the air space with its impregnation of particles, were the only element entering into the question, istances in these two cases should be exactly [illegible]. experiments have been made with arcs of different lengths lectro-motive force being also varied so as to keep the strength constant, with the result that allowing for a counter E.M.F. of 39 volts there remained a resistance , as we should expect, varied proportionally with the length arc, and affording thereby a demonstration of the actual ce of the counter E.M.F.

e great practical lesson to be derived from a knowledge of fect is that the E.M.F. of the current which is passed through op must always exceed 39 volts, or it will fail to maintain , in just the same manner that an E.M.F. exceeding 1·47 must be employed to decompose water. It is in fact usual vide an E.M.F. of between 44 and 50 volts for each lamp, nal or net resistance of the arc itself, that is of the air space ting the carbons when they are in the normal position for g, or at a distance of about 3 millimetres apart, being ly estimated at something between one-eighth and one-half ohm.

e resistance of prepared compressed carbon varies with fferent makers, the resistance of one specimen amounting o times that of a similar piece of pure copper, or nearly 4,000 ms per cubic centimetre. The specific resistance of the atively impure and more crystalline gas retort carbon has own to be about 17 times as [illegible] that of the prepared n. The actual resistance of th[illegible]ns ordinarily r arc lamps is about 0·15 [illegible] In order to this they are frequently co[illegible] layer of deposited electrolytically. [illegible] be taken metallic deposit is very [illegible] melt for stance up the rod, and [illegible] fused [illegible] the [illegible] quantity [illegible] [illegible] green [illegible] method of [illegible] [illegible]derably, [illegible]

most cases regarded as trade secrets. Generally, however finely pulverised coke forms the basis, this being intimately mixed with pure carbon powder derived from the destructive distillation of some such organic substances as gas tar, pitch or bitumen. An adhesive substance, such as a syrup of cane sugar and gum, is then added to make a paste, the rods being shaped by forcing the mixture with considerable pressure through a die plate. The rods so formed are then baked in an oven a number of times, to decompose the carbonaceous compounds, and drive off the volatile constituents. Immersion in syrup usually takes place between the bakings. But great care is taken to remove any foreign substance from the ingredients, and so to ensure the production of a homogeneous rod, for, as will have been already gathered, the presence of foreign bodies in the arc causes fluctuations in its luminosity, and considerable variations in its colour.

The chief requirements which it is necessary that a carbon rod should fulfil are then, that it should be dense, that its molecular or mechanical structure should be uniform, that it should be pure and that its electrical resistance should be low. The diameter of the rod varies with the light it is required to give or the current it is required to carry, those most frequently employed ranging from 7 to 10 millimetres in thickness, and these give an actual luminosity of about 875 candle-power per $\frac{2}{3}$ horse power absorbed, and approximately this may be taken as the power required and the actual amount of light emitted by an ordinary arc lamp. The usual practice of referring to the light of such a lamp as being of 2,000 or more *nominal* candle-power is, therefore, very misleading. The use of globes still further reduces the actual amount of light obtained from the lamp.

The proportion of light cut off by globes has been determined to be :—

For clear glass . . .	about 10 per cent.
„ light ground glass . .	„ 30 „
„ heavy „ „ . .	45 to 50 „
„ strong opal „ . .	50 to 60 „

Assuming an arc lamp to give a light of 875 candle-power when the current strength is 10 amperes and the E.M.F. 50 volts

ill be evident that this amount of light is produced at a cost of watts, so that were a lamp to consume one electrical horse-wer or 746 watts, it should yield a light of about 1,300 candle-wer. Allowing for the various losses in the conversions, it may taken that on an average arc circuit, the engine indicates one se-power for each ordinary or 875 candle power lamp.

The Jablochkoff 'candle,' which was devised by M. Paul lochkoff in 1872, and which caused considerable excitement the Paris Exhibition of 1878, is undoubtedly the simplest form arc lamp yet introduced, although, as it is not economical, it used less extensively than it otherwise would be. The candle nsists of two pencils of prepared carbon about 22 centimetres g and 4 millimetres in diameter, fixed parallel to one another t separated by a strip 2 millimetres thick, of some fusible n-conducting material such as kaolin. Pieces of split brass bing, 5 centimetres long, are placed over the lower ends of e carbon pencils and serve to form connection with the holder ich is attached to the base of the lamp. The upper ends of e pencils are scarfed, and a small lighting fuse consisting of a ste of plumbago and gum serves to connect them together elec-ically and affords a path for the initial flow of the current. This fuse speedily consumed and the arc established. The consumption of the positive, as compared with the negative carbon being with a direct current approximately as 2 : 1, an alternating current is employed, so that the pencils are uniformly consumed, the in-sulating material also being burnt at the same rate. Each candle ... an hour and a half, and owing to the interposition ...g strip, that is, to the separation of the carbons, a ... ing been once extinguished cannot be re-ignited ...ghting fuse is added, or the pencils temporarily ...ece of wi... another piece of carbon.

... s on a circuit through which a ... the potential difference neces-... being about 42 volts. The ... energy is therefore about 336 ... on an open light, a lumino-

... andles, generally four, in a

lamp, and consume them in succession. In this way, the light can be maintained for six hours without any attention being given beyond that of turning a switch, so as to divert the current from one candle to another. The form of candle-holder most frequently employed consists of two short rigidly fixed pillars, one of them being slotted so as to allow a small play for a triangular piece carrying the socket for one of the carbons, the other socket being cut in the other pillar. A stiff flat spring presses against the free corner of the triangular piece, which can be moved to and fro in the pillar. On pressing the candle in between these pillars, a good mechanical support, as well as good electrical contact, is afforded.

There are two kinds of lamp bracket for supporting the holders. In one of them, one pillar of each of the holders is electrically connected to a common terminal, the other pillars being connected each to a separate terminal, so that at least five leads are necessary. In the other type each candle has a separate holder, each holder requiring two terminals and a distinct pair of leads from the switch.

Sometimes a switch is placed on or near each lamp, but it is more general to divide the lamps into a number of separate circuits, each circuit comprising four lamps joined together in series and manipulated by a single switch placed in the dynamo-room.

An automatic arrangement is also employed to avoid the risk of burning the candles right down to the sockets and so causing a disconnection. The apparatus consists of a vertical solenoid with a core which is provided with two pairs of contacts. Should the circuit be broken by one of the candles 'going out,' the core falls and two of the contact points fall into mercury cups and complete the circuit of an electric bell. At the same time the other pair of contacts drop into mercury cups which complete the circuit through the second series of lamps. The attendant has then only to shift the leading wire to the terminal block of the next circuit in readiness for his next act of negligence.

The Jablochkoff system has very few advocates in England, chiefly on account of its cost, but it is a very simple system and one which finds great favour in such places as the Indian palaces,

where money is not scarce, and where skilled labour is practically unprocurable. Other forms of electric candle have been devised, but as they are all now extinct, we need not pause to consider them.

Another class of arc lamp, frequently called the semi-incandescent, used, however, with a direct current, is typified by the Werdemann lamp, which consists of a large rounded block of carbon connected to the negative lead and supported by a hinged bracket. The positive lead is connected to a thin pointed carbon rod, and, by means of a weight attached to a cord working over a pulley and fastened to its lowered end, this thin rod is kept in contact with the hinged block. Both carbons become incandescent at, or in the vicinity of the point of contact, and a small circular arc is struck. The rod is of course somewhat rapidly consumed, and a hole gradually formed in the carbon block. Great things were expected of this lamp, but it did not prove economical; it was very variable, flickered considerably, and is now practically obsolete.

Our chief object in referring to these lamps, was to give some little idea of the channels into which men's minds were directed in their earlier efforts to 'subdivide' the electric light, or more correctly speaking, to maintain a number of comparatively small lamps on one circuit.

Coming now to the question of arc lamps in their present state, it would be convenient if we were able to classify them, or divide them into a few distinctive types, but there is absolutely no simple or natural classification, and a complicated or forced division would be undesirable.

Many efforts have been made to obtain a precise but comprehensive classification, with the result that there are virtually as many classes as there are lamps. It would be possible to divide the lamps into two classes, viz., those used in series, or on a circuit through which a *constant current* is sent, and those used in parallel, or which have a *constant potential difference* maintained at their terminals. The latter kind are comparatively simple, but any lamp of that class could be transferred to the other by an alteration in the winding of the coils and by the addition of a 'cut-out' device, to automatically short-circuit the lamp, in the event of a disconnection in the arc-circuit.

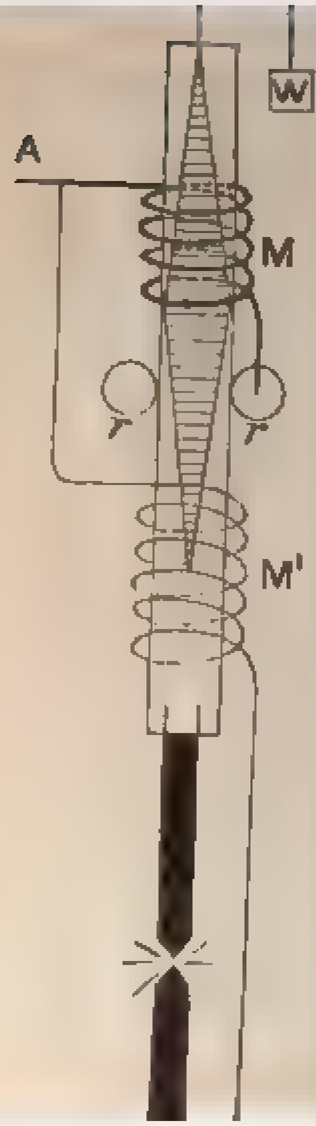
This system of classification, therefore, can scarcely be said to be satisfactory. It is, however, an important feature that the series system is characteristic of the arc lamp, owing to the fact that the main leads need only be small as compared with those necessary for parallel working. With the small current usual on a series circuit, the loss due to the resistance of the leads is trifling as compared with the loss that would be experienced were the same leads used for parallel lamps. For this reason parallel arc lamps are not often used, although they have the advantage that they can be so adjusted as to render it possible to join them in parallel with incandescent lamps. In all cases it is essential that the lamp should automatically 'strike' its own arc, or cause the carbons, when in contact, to separate to the required distance and this action must perforce be controlled by the main current, that is to say, the separation of the carbons must always be brought about electrically, and the coil used for the purpose must always be placed in the main circuit. This coil is usually referred to either as the main, or the series coil, the latter term being employed because the coil is joined in series with the carbons. When lamps are joined up in parallel, a small resistance coil is placed in series with each lamp for steadying purposes. Without this resistance, a slight variation in the length and resistance of the arc, or the reduction in the resistance of the carbons as they burn away, would cause a sensible variation in the current strength; but the use of a resistance coil reduces the percentage of the variation in the resistance of the particular branch, and therefore keeps the current strength more nearly uniform. To compensate for the loss of power in the 'steadying' resistance, the E.M.F. provided is about 5 volts higher than that provided per lamp when joined in series. With lamps joined in series this extra resistance is unnecessary, because when the resistance of any one lamp varies, the current strength is not appreciably affected; the other lamps in circuit with it, in effect, act as a steadying resistance, and tend to keep the current strength constant.

If the source of light is for focussing purposes required to remain stationary, which is, for lighthouse or lantern work, of paramount importance, both carbons must be automatically movable, at their respective rates of consumption; but when this is not absolutely

[illegible]

possible to divide lamps into alternating and [illegible] lamps, but this classification would be meaning[illegible] any fundamental difference in the principles [illegible] involved. One point may however here be [illegible] it is that with lamps used on alternating-current [illegible] say that the cores of the electro-magnets should [illegible] ated in order to minimise self-induction and [illegible] enable them to respond quickly to the [illegible] le to divide lamps into two classes, viz. those in [illegible] ing forward of one or both of the carbons is [illegible] ally, and those in which the controlling agent is [illegible]

But we are here met with another difficulty [illegible] which mechanism is employed for feeding [illegible] n of the current to release or start that mechanism. [illegible] 'mechanical' lamp would be one in which the upper [illegible] downwards by gravitation, that is, in virtue of its [illegible] hen the current passing through the coil used for [illegible] maintaining the arc is instrumental in overcoming this [illegible] ation; and we shall see in the [illegible] simplicity is in great measure [illegible] however, a parallel lamp [illegible]. When the lamp is used on a series circuit [illegible] second coil, which is acting in opposition [illegible] feeds the carbons forward when [illegible] too great. This [illegible] forming a [illegible] [illegible]



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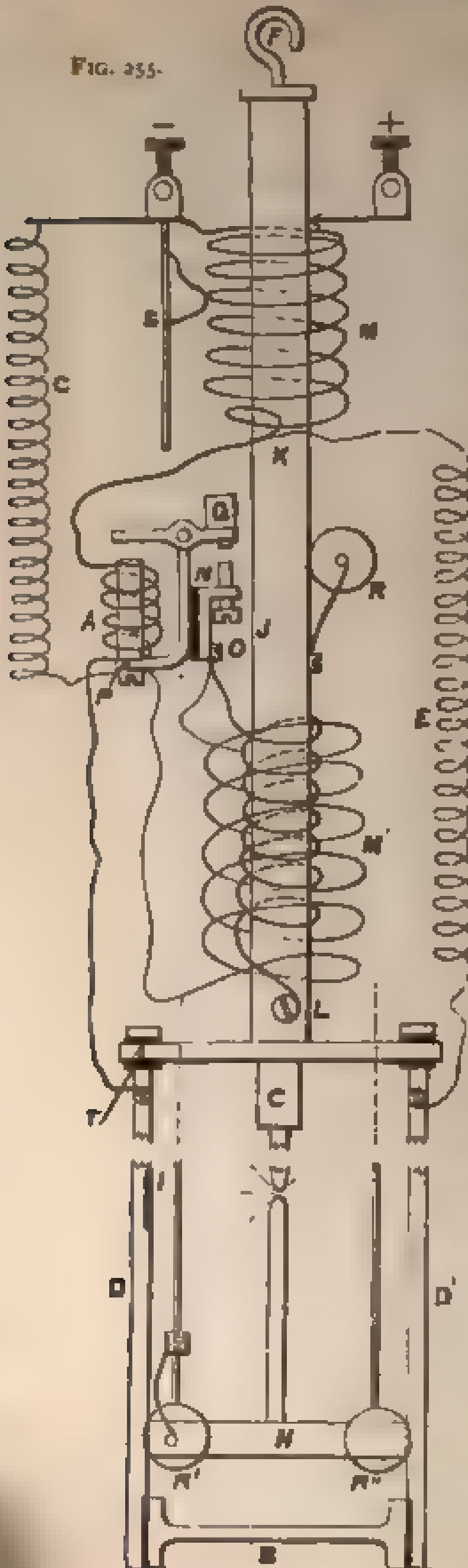
The resistances of the coils M and M^1 are so adjusted that, the arc having been struck and having arrived at the proper length, the action of the coils upon the core is exactly balanced. Any increase in the resistance of the main or series circuit, caused by an increase of the length of the arc, disturbs this balance, increasing the current through the shunt coil, whence the core, with the upper carbon attached, is attracted downwards by the shunt coil, and in descending again restores the balance, readjusting the arc to its previous dimensions. It will thus be seen that in the event of a disconnection in the arc circuit such as might happen before lighting up, the coil M^1 takes the whole of the current, and continues to draw the core down until the two carbons enter into contact. Immediately this happens a heavy current passes through M at the expense of M^1, and the core and upper rod are raised just sufficiently to establish the arc. It may here be observed that were the core made of a simple cylindrical rod of iron, it would have a tendency to balance itself, or take up its position in the middle of the electro-magnetic field produced by the two coils; and although a variation in the magnetisation of either solenoid would move the core away from that position, it would manifest a tendency to return to it, and in so doing cause fluctuations in the arc. By using the conical core this difficulty is overcome, because as the magnetisation of the preponderating solenoid increases, and attracts the iron, it acts upon a gradually increasing core, so situated that it can never get into its 'best position,' but remains steady at any point in a comparatively long range.

Fig. 254, while serving to illustrate the general principle involved in differential lamps, is really a skeleton diagram of the Pilsen, (which was invented by Messrs. Piette and Krizik of Pilsen, a town in Bohemia,) and which, while simple in construction, works with remarkable steadiness, even under somewhat considerable fluctuations in the current. It has also the advantage that it is practically noiseless.

It has recently passed into the hands of the Gwynne-Pilsen Co., who have simplified some of its details and effected other structural improvements without, however, interfering with its fundamental principle.

Fig. 255.



A detailed diagram of the lamp is given in fig. 255. The coil-frame J and casing are electrically connected to the positive terminal +. From J the current is transmitted by contact rollers R to the inner brass tube C (containing the double conical iron core), and thus through the holder to the positive carbon. Thence it passes through the arc to the negative carbon holder H, and from thence through the contact rollers R′ R″ to the negative guide rods D, D¹, both of which are insulated from the bottom plate of the lamp, as well as from each other at B. The current being thus divided, one part (the lesser) passes through the iron wire coil E, and the greater part through the automatic cut-out coil A, these two branches reuniting at K, and thence passing through the main coil M to the negative terminal marked −, from which it is carried to the positive terminal of the next lamp in series, or the negative terminal of the dynamo, as the case may be. The negative holder is supported by two cords which pass over pulley wheels and are connected to the brass tube containing the core. This is more clearly indicated in fig. 256, where the cords are shown connected to the rods attached to H, R R′ being the pulley wheels.

of these wheels, R′, has very fine teeth cut round it, into h the click, which is to be seen above the wheel, engages, so allow the wheel to rotate freely for feeding, but to prevent oving in the reverse direction. The cord, therefore, during eparation of the carbons has to *slide* along the groove, suffi- t friction being in that way introduced to prevent sudden or y separations.

Were the two holders exactly equal in weight they would counter- nce, but in the more recently constructed lamps, the positive der is about 1½ ounce heavier than the negative, so that when current is flowing the carbons run together.

The action of the series current then is to draw the iron core, hich the positive carbon is attached, up into the coil M, thus king and maintaining the arc. In order to regulate the lamp, hunt-current is taken from the screw L, and passed round a noid of stout copper wire, to the insulated bracket O, and re- ning from thence through the shunt-coil proper M^1, consisting many turns of fine copper wire (wound in the same direction as spiral of L), having its other end attached to the bracket P of automatic cut-out, from whence it passes through a coil of t German silver wire G to the terminal marked –. The number onvolutions of the coil M^1 and their resistance are so propor- ed that (when the arc has been drawn to a length of about ch) the attractive action counterbalances that of the main and the small extra weight of the positive holder. Equili- being thus established, the arc is maintained at its normal and resistance, so long as the current is kept constant. If y accidental cause (such as the fracture of a carbon, me- injury, or the breakage of a cord), the main current w from C to D [illegible] D^1; then the magnet A of the auto- ut fails to ho[illegible] its armature, which by reason of its unat[illegible]d falls in the opposite direction, a [illegible] the screw N on the insulated [illegible] the main current *viâ* L, O, N, Q, [illegible] –, and so preventing a com- [illegible]on of the shunt-coil M^1.

[illegible]d with a strip of ivory insula- [illegible]ns are nearly burnt out, the

contact roller R^1 ceases to make contact, the current ceases to flow round the magnet A, Q falls, and the lamp is cut out of circuit. The function of the alternative path from R through D^1 and of its iron resistance E is that when the lamp is burning, the resistance E causes the greater part of the current to pass *viâ* D, thus securing the efficient action of the magnet A, and preventing the lamp from becoming prematurely cut out. When owing to exhausted carbons the lamp is in process of cutting out naturally, the contact roller R^1 in passing from D on to the insulating strip I, would carry an arc after it from R^1 to D, were it not for the temporary path afforded from D^1 through E, until such time as the main current had been diverted through the path L, O, N, Q, G. The German-silver coil, G, has no action upon the working of the lamp; it is a compact form of resistance, equivalent to the apparent resistance of the lamp, to be thrown into the main circuit, when the lamp is cut out automatically; it is superfluous with a self-regulating dynamo.

A view of the interior of the lamp is given in fig. 256, in which the lettering corresponds to that employed in the diagram, fig. 255. It will be observed that a means of final adjustment is provided by the movable contact S, which can be used to cut out one or more of the convolutions of the main coil M. The friction roller is here lettered *r*, and as already mentioned, R R′ represent the pulley-wheels over which the cords connecting the positive and negative holders together, are passed.

A sectional view of another form of the lamp is given in fig. 257, in which the two coils M and M^1 are wound on the same bobbin, but in opposite directions. The long conical core is clearly shown at D. The negative holder is suspended in the same way as in the bi-conical form, but the pulleys and other parts such as the cut out are not shown in this figure. The lamp is also made with horizontal carbons, so as to render it suitable for rooms with low pitched roofs, and it will be seen that the absence of mechanical control facilitates considerably the alteration in the design. It should be added that the workmanship of the Pilsen lamp is of the highest order; the finish is unusually good, and all pulleys, rods, and the working parts generally, are electroplated.

Another very simple and efficient lamp is that invented by Mr.

FIG. 256.

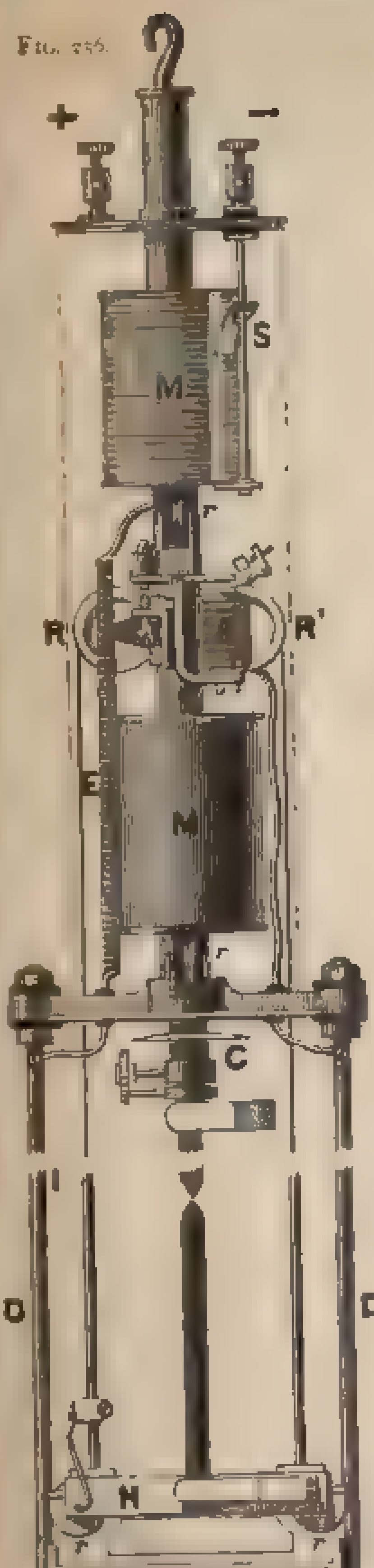
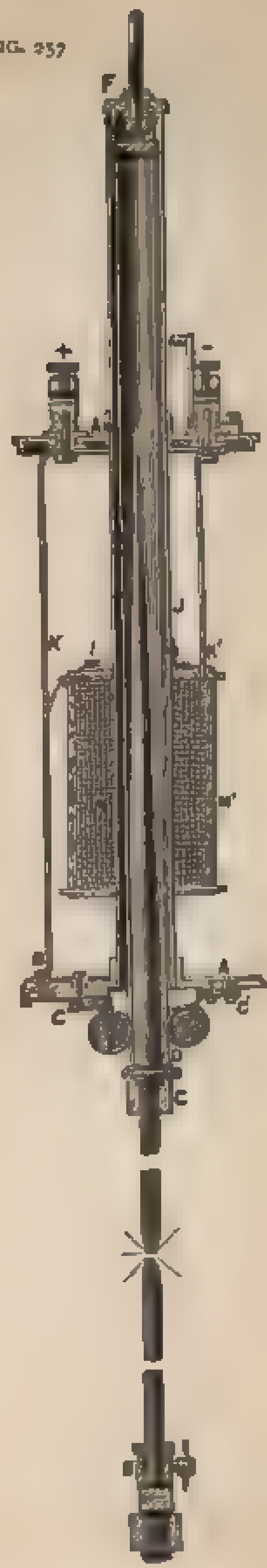
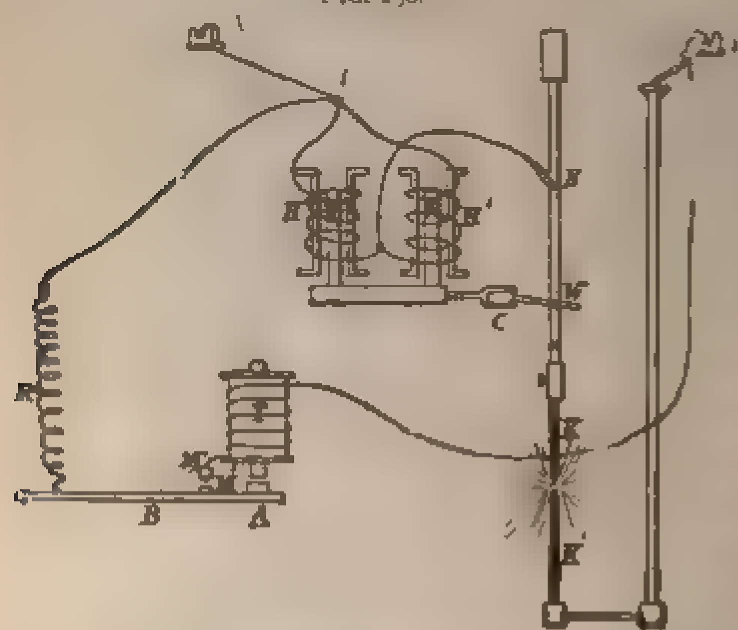


FIG. 257



C. F. Brush. It was one of the first and it certainly remai[ns one] of the best of modern arc lamps. A great feature in its [design] is the extreme simplicity of the mechanical contrivance. [Its] principle is illustrated in fig. 258. The terminals X Y take the form [of a] pair of brass [hooks,] which, by [being] dropped over [hori]zontal [p]ins [on the] under side of [a sus]pending boar[d, hold] the lamp at [its place in] the main circu[it. The] negative car[bon] is fixed, and [is] gradually co[nsumed as] the arc is [burning, being] lowered in [proportion,] the upper [posi]tive carbon K, falling at a corresponding rate.

Fig. 258.



The current enters the lamp at the positive terminal [X and] divides at V in the main circuit, passing through the low [resistance] coils H H′, in parallel in such a way as to generate pow[erful] opposite poles at the lower ends of the solenoids. On le[aving the] coils the currents reunite, and passing by a wire to th[e upper] carbon holder N, traverse both carbons, the lower of [which is] connected to the negative terminal Y. The shunt circu[it, the re]sistance of which is 450 ohms, is made by a thin wire pa[ssing from] X round the bobbins H H′ in series, then round the cut-o[ut] T, from which it passes direct to the terminal Y. The th[in wire on] H H′ is wound outside the main coil. Connection is a[lso made] between V and the pivoted lever B, by means of a wire a[nd resist]ance spiral R, but this will be again referred to presently.

Assuming the carbons K K′ to be in contact, the p[assage of] the main current through the coils H H′ causes the soft i[ron cores] N S and their horizontal yoke-piece to be drawn upwa[rd. The] yoke-piece is provided with a fork C, which tilts the wash[er] W, causing it to seize the carbon holder and raise it suffi[ciently]

the arc. Under normal conditions only about 1 per cent. total current passes through the shunt coils, but when the creases in length and thereby raises the resistance of the ircuit a proportionally larger current passes through the long ire coils on H H′. Being wound in the opposite direction few turns of the main coils, the shunt coils cause a diminu- of the magnetisation of the cores or plungers N S, which ore fall, and, causing the clutch W to loosen its grip of the , allow the positive carbon to fall, by the force of gravita- until the length of the arc is so far reduced as to re-establish ormal division of the current through the main and shunt We see then that the function of the thick wire coil is to e clutch and strike the arc, while that of the shunt coil is to the clutch, allowing the rod to slide and feed the carbon vards. As a rule these reactions take place so gradually e upper carbon is maintained at a uniform distance from ver, and is simply fed at a rate corresponding with the con- ion.

e 'cut-out' coil T performs a most important function. vident that should one of the carbons be burnt away or , or should from any other cause the maintenance of the arc e impossible, some device is necessary to introduce into the an alternative path of about the same resistance as the arc . The way in which this is accomplished in the Brush lamp nious. It will be remembered that the shunt circuit includes of many turns of thin wire on the bobbin, T. Now when in circuit is broken, the whole current has to pass through unt circuit, and the coil T is so adjusted that when this sed current passes through it, but not otherwise, its core es sufficiently magnetised to raise the armature A, and with lever B. This lever carries the small contact stud M, is on rising makes contact with another stud M′, which is con- to a short thick wire coil round T, the other end of which nected to Y. It follows that under such circumstances a low nce circuit is established from V, along R, and B, to M, and to Y.

re it not for the high resistance of the shunt coils, they be employed for this purpose, but under the circumstances

such a plan is obviously impracticable. Of course as the main circuit is disconnected, the positive carbon-holder is not interfered with by the clutch, and can therefore, if only a portion of the carbon has been broken off, descend and re-establish the arc, when the current flowing through the thick coil on T will be diminished and the cut out circuit disconnected.

Usually the Brush carbons are a foot long and last for eight hours or thereabouts. When, however, a longer period of lighting is likely to be required, lamps with two pairs of carbons are employed. The device for 'changing over' from one pair to the other is purely mechanical and is illustrated in fig. 259.

FIG. 259.

The positive carbon-holders R^1 and R^2 are parallel one to the other, and each is furnished with a washer clutch, as shown at W^1 and W^2. These clutches are operated by a small frame K, which is supported by the lever (shown in section at L) attached to the plunger or soft iron core of the striking and feeding solenoids. By the very simple device of making one of the forks in the frame K higher than the other, this higher fork tilts its clutch before the other begins to act, and consequently lifts its corresponding carbon holder a greater distance than does the other. At the moment when the first carbon is raised, it is short-circuited by the other, which the next moment is also raised. The arc then establishes itself across the lesser distance, and in all subsequent feeding and controlling movements the pair of carbons across which the arc was first started are alone affected, because, although both positive carbons are raised and lowered together, the ends of the reserve carbons never come into contact, and the E.M.F. is insufficient to start an arc across the air space which separates them. When the one pair of carbons have been so far consumed that they cannot meet when the frame falls, the circuit is completed through the reserve

[car]bons, and the arc established, after which it is maintained by [the] same apparatus acting in the same way as with the first pair.

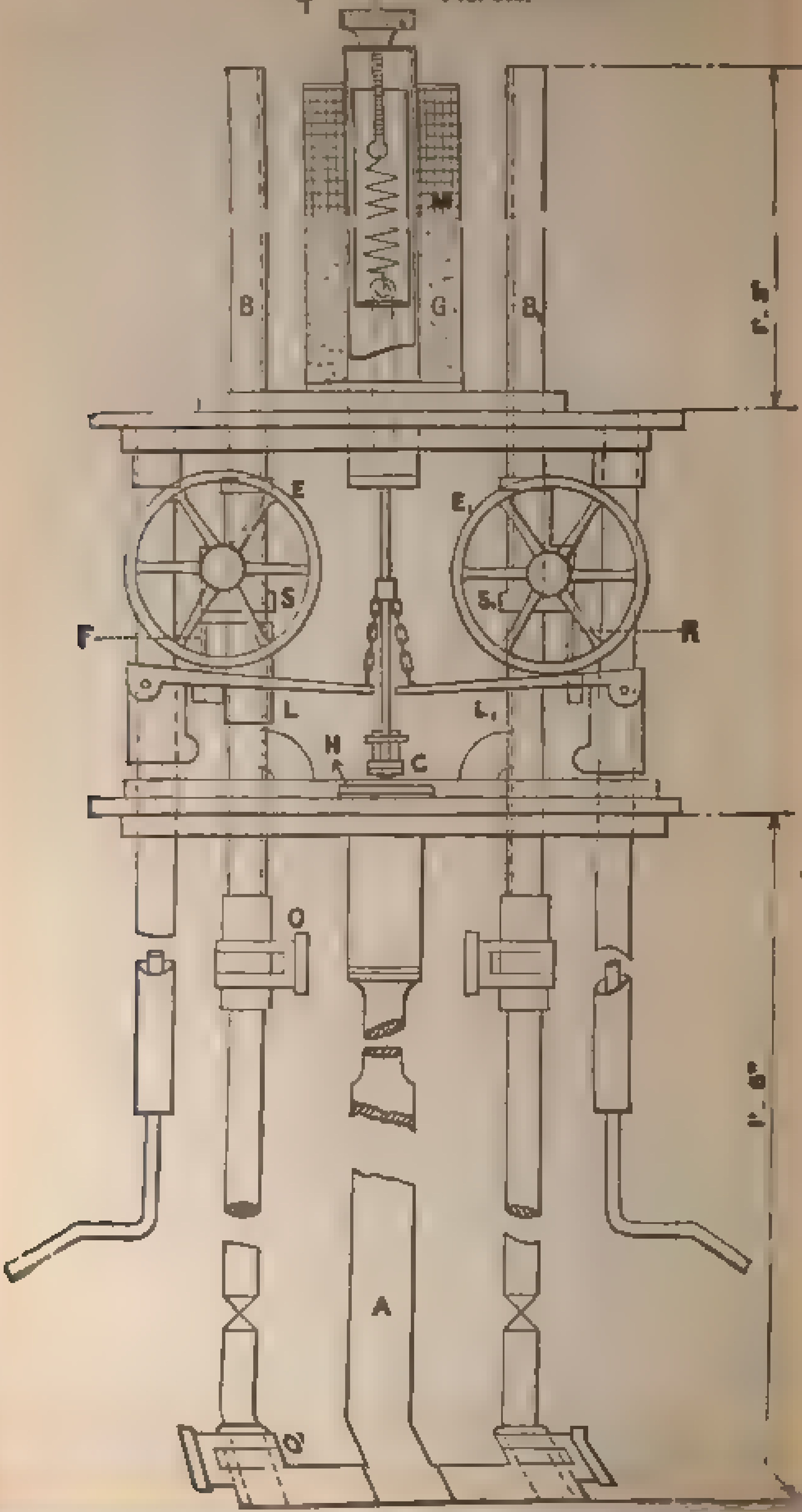
The construction of the double arc lamp invented by Messrs. [Cro]mpton and Crabb is illustrated in fig. 260.

The two positive carbons are carried by the rack-rods B and B_1. [Slid]ing on each of these is a light gun metal sleeve, S S_1, carrying [spin]dles, to which are attached the two large brake wheels, E E_1, [and] between them the pinion which gears into the racks. These [bra]ke wheels rest upon a pair of levers, L L_1, the outer ends of which [are] pivoted to the framework of the lamp, their inner ends being [con]nected by links to the core of the solenoid, which is placed in [a ce]ntral position vertically above the two inner ends of the levers. [Thi]s solenoid is differential, G being the shunt and M the main [coil], and the core is partially supported by a spring. The tension [of t]his spring can be regulated by means of the screw T, which is [tur]ned to the right to increase its length, and to the left to de[crea]se it.

Projecting vertically downwards from each sleeve, S S_1, to a dis[tan]ce from the centre of the spindle about equal to the radius of [the] brake wheels, is a stout pin or finger, F F_1, the action of which [is in]teresting.

Suppose the rack-rod to be drawn up, then if the lever be [rais]ed by the solenoid above the horizontal position, the whole [wei]ght of the rod and carbon is supported on the edges of the [bra]ke wheels, and the friction of them on the surface of the levers [is s]ufficient to prevent their revolution; hence this rack-rod cannot [run] down. But if the levers be below the horizontal, then the [wei]ght is carried by the finger projecting from the sleeve, as shown [at F]; the wheels are free to turn, the rack runs down, and continues [to] do so until the positive and negative carbon points come in [con]tact. Now, if the current be switched on by its passage [thro]ugh the main wire of the solenoid, the levers rise, striking the [F], and at the same time applying the brake to the wheels. The [com]bined action of the shunt and main currents on the solenoid [will] automatically adjust the length of the arc. If this becomes [too] great the increased current through the shunt draws down the [core] and levers, the brake wheels are left free to revolve, and the [arc s]hortens. On the other hand, if the carbon points be too close

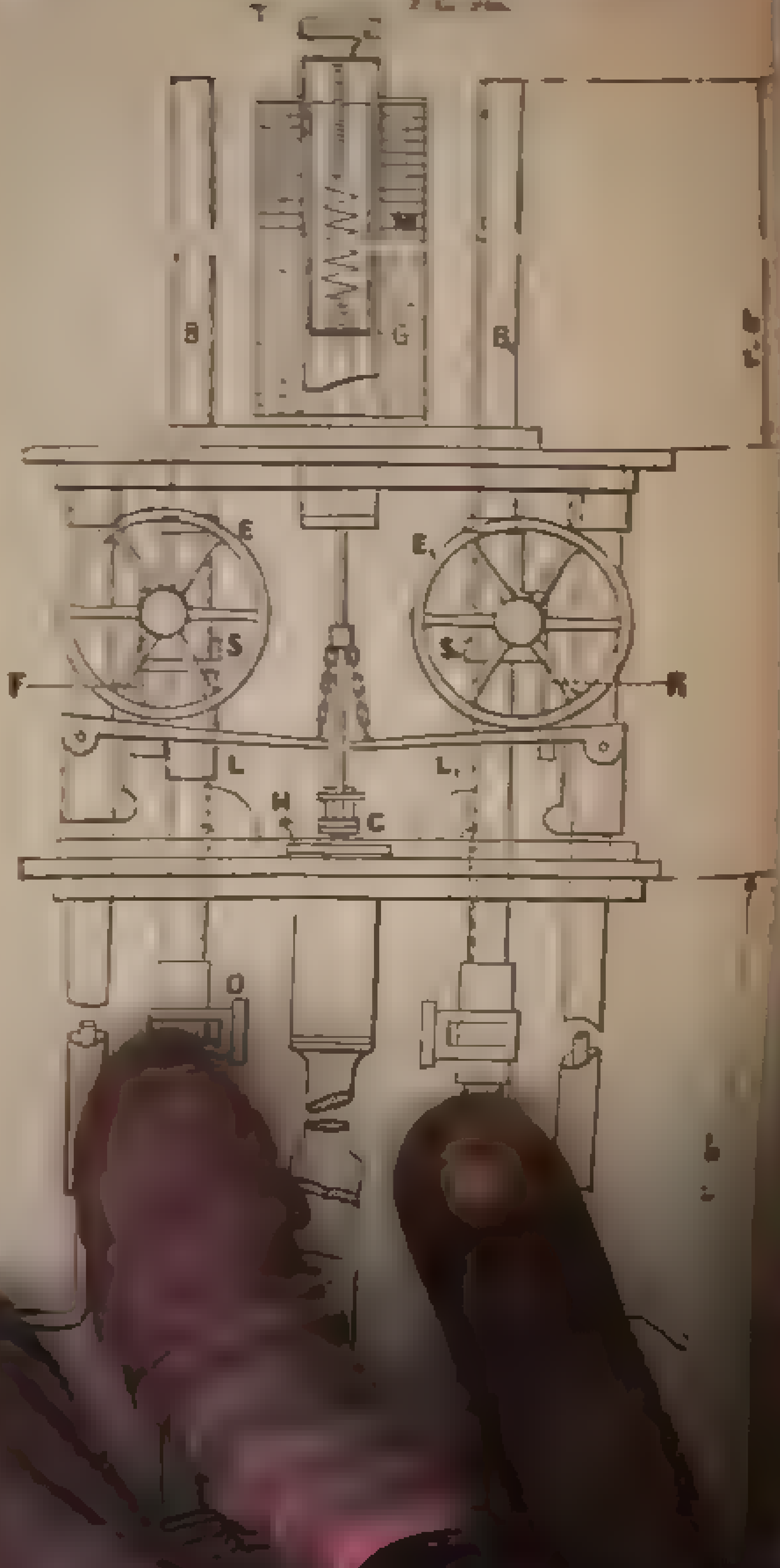
Fig. 260.



Pilsen Lamps

256

Fig. 257


B
G
B
E
E,
S
S,
F
R
L
L,
H
C
O

is attached to the frame H D. The pinion G gears into the larger toothed wheel E, on the axis of which is a pinion C engaging with the rack R of the positive carbon rod. This rod carries a weight W, which enables it in descending to lift the negative rod Y X. When no current is flowing the brake lever N rests on the screw S, which releases the brake wheel and allows the carbons to come into contact. The current enters at the positive terminal on the right hand of the figure, passes through the framework of the lamp to the rod Y, and thence to the positive carbon. It returns from the negative carbon by the insulated rod X and flexible wire attached to it, passing through the thick wire coil on A, and from this to the negative terminal. The magnet attracts K, raising the frame H D, thus causing the lever N to grip the brake wheel and, by turning E and C, to raise Y and lower X for the purpose of separating the carbons and forming the arc. As the carbons consume, the difference of potentials at the terminals rises and the current in the fine wire coil round A, which is connected as a shunt to the lamp terminals, increases. This weakens the electro-magnet A and allows the frame H D to fall and the carbons to approach. When the lever N comes in contact with the screw S, the brake is released, allowing the carbons to approach as the consumption continues. If the carbons burn out, or if from any other cause the circuit through them is broken, the frame H D drops on the contact pillar M; this completes the circuit from the lamp frame through the German silver resistance R to the negative terminal, thus preventing a break in the continuity of the circuit when several lamps are joined in series.

The Brockie-Pell arc lamp is illustrated in fig. 263; the main and shunt coils are wound on separate bobbins fixed parallel to one another, the main or series coil being that on the left side of the figure. The two cores pass through the ends of, and operate a 'see-saw' lever which is pivoted at its centre. The two carbon-holders are connected by a cord passing over a pulley wheel pivoted on the base of the lamp-case. The upper or positive holder is provided with a rack-rod which gears into a pinion; the spindle of this pinion works in the frame of the lamp and carries a comparatively large wheel having a strong broad rim, against which a brake in the form of a small leather roller is

applied. The lever carrying this brake turns on the weighted shaped lever, which is loosely pivoted but moves solidly brake wheel, its descent being, however, limited by a sto

Fig. 263.

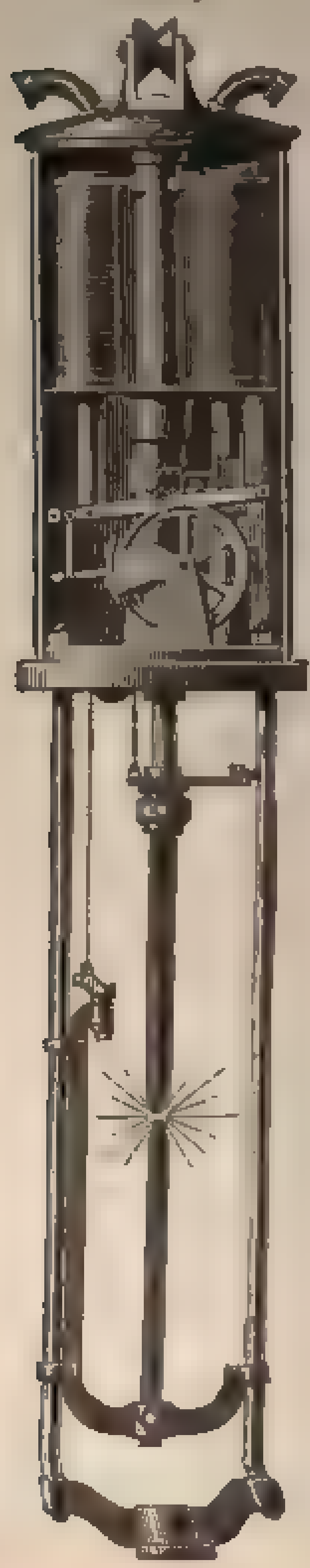
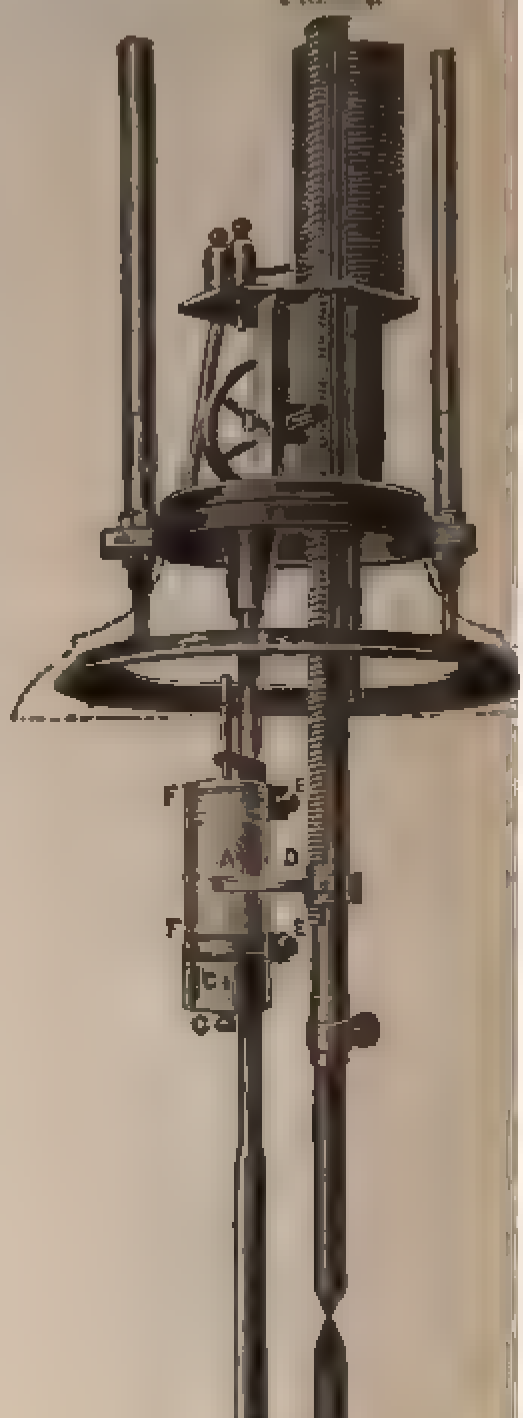


Fig. 264.



applied. The lever carrying this brake turns on the
shaped lever, which is loosely pivoted but moves so
brake wheel, its descent being, however, limited by

FIG. 263.

FIG. 264.

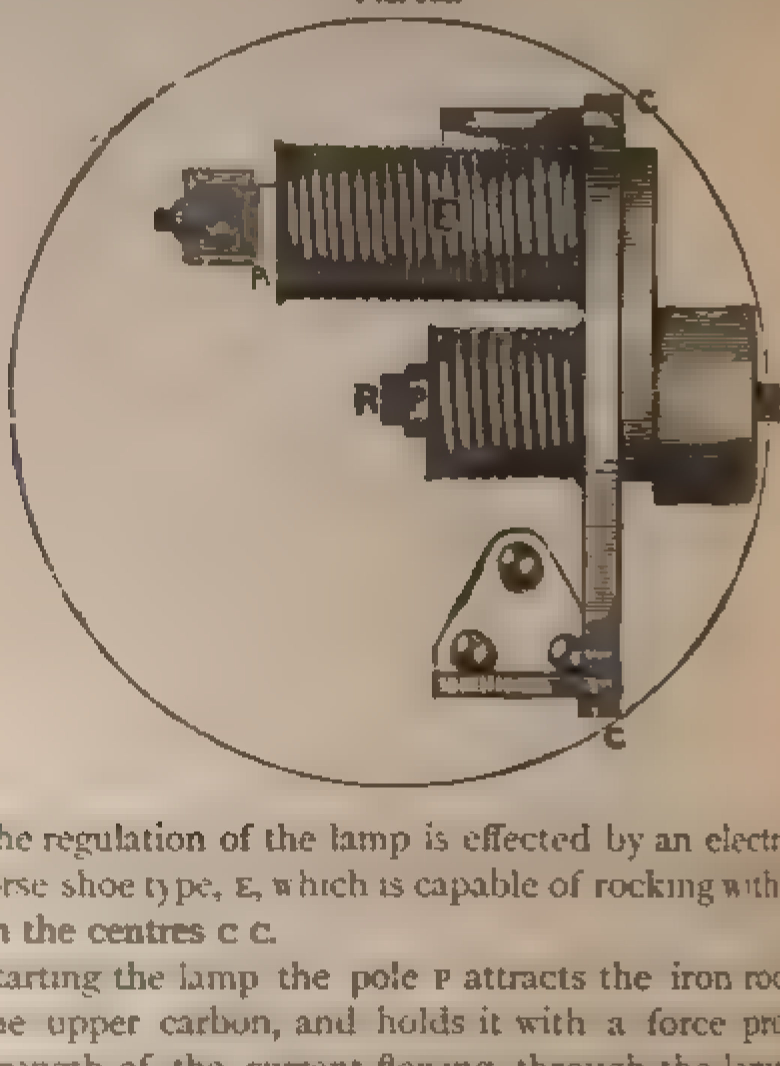
of the brake-lever is connected with the link supported
saw lever. The action of this mechanism [illegible]
. On the passage of the current the [illegible]
nd of the lever, applies the brake to the wheel, and raises
e carbon, the negative carbon being caused to [illegible]
e time. The arc is therefore established. As the arc
and the main current diminishes, the shunt current
and the other end of the see-saw lever is elevated.
dy the brake lever is depressed, the brake wheel re-
d the carbons allowed to feed together. [illegible]
place readily, the feed being practically continuous, and
dy light is the result. The usual arrangement for causing
rbon holders to operate with any particular strength is
y means of weights. As compared with the majority of
e mechanism is simple and strong.

264 is illustrated a form of arc lamp devised by Mr. I
for workshop use. The lettered portion of the apparatus
form a part of the lamp, but is attached for experimental
and will be explained presently.

lower carbon is fixed, and the upper one is carried by a
which engages with a pinion carried on a horizontal
. On this same spindle, and just behind the pinion on the
is fixed a large grooved wheel round which passes a small
One end of the chain carries a peculiarly shaped weight,
e other end is fixed to the lower extremity of the core of the
ing solenoid, seen to the right at the top of the figure. Fig.
ustrates this arrangement more clearly, and also gives a sec-
the weight. H is the rack-rod which carries the upper carbon,
gages with the pinion K, while L is the large grooved wheel,
same spindle as K, round which the chain C passes once.
e point at which the chain is fixed to the core of the regulat-
[illegible] is required to separate the carbons and
e arc, the [illegible] sucked upwards into the solenoid, and
[illegible] causes the wheel L to revolve. This
[illegible] k rod by the pinion, on the well-
[illegible] and the upper carbon being lifted
[illegible] struck. The chain is prevented
[illegible] weight at its lower end. This

parallel working, and has, therefore, neither a shunt co... nor a ... out It is consequently very simple in construction, as will be gathered from the plan given in fig. 266, and the elevation in fig.

FIG. 266.



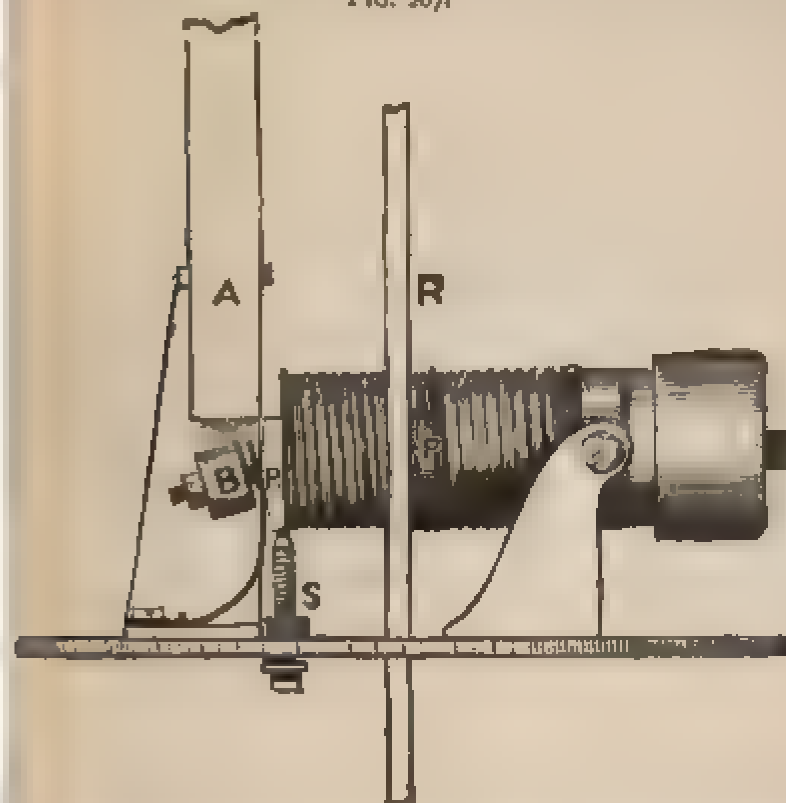
267. The regulation of the lamp is effected by an electro-magnet of the horse shoe type, E, which is capable of rocking within certain limits, on the centres C C.

On starting the lamp the pole P attracts the iron rod R which carries the upper carbon, and holds it with a force proportional to the strength of the current flowing through the lamp. At the same time the other pole, P_1, is attracted towards the fixed armature A, and the magnet moving upwards carries the upper carbon rod with it, and thus strikes the arc.

As the carbons are consumed the resistance gradually increases, and the current diminishing at a corresponding rate there is less magnetic attraction towards the fixed armature; the rocking magnet then falls to its original position of rest, supported by the stud S (fig. 267), and causes R to approach the lower carbon and so to maintain the arc, the current strength being at the same time increased proportionally.

consumption of the carbons is continued and the length
e therefore increased, the current is again diminished.
diminution the magnetism is so reduced as to allow the

FIG. 267.



older R to slip until the arc reassumes its proper length, normal current is re-established, when the magnet is once bled to support the weight of the rod.

actice the rod is continually slipping by imperceptible and compensating exactly for the consumption of the

oid sudden jerks in the action of the rocking magnet, a brake B is employed, which introduces friction in inverse n to the length of the arc. The two carbon holders are d by a cord passing over a pulley wheel, so that the two pproach or recede simultaneously.

amp is constructed in various forms, but in all of them simplicity of parts is maintained. The globe is fitted to sliding rods and can be drawn down out of the way so ose the *carbon-holders* and facilitate the renewal of the

parallel working, and has
out. It is consequently
gathered from the plan gi

267. The regulation of
of the horse shoe type,
limits, on the centres C
On starting the lamp
carries the upper carbo
to the strength of the
same time the
ture A, and th
rod with it, a
As the car
creases, and the
is less magnetic a
magnet then falls
stud s (fig. 267), a
so to maintain the
time increased propor

such as
h as placing
enclosed in
a substance
n this case, the
arkably neutral
ngement as this
n fact impracti-
ise, the carbon
te or gas-retort
ns of the artifi-
nche cell, were
ly small

Men were not long in conceiving the idea of employing the heating effect of a current upon a conductor for illuminating purposes, and patents based upon this principle were taken out nearly fifty years ago. But these early efforts were one and all of them failures from a commercial point of view, although some of them were identical with many of those of a comparatively recent date. It was seen that a conductor of high specific resistance was necessary, and this limited the number of materials available. This number was further reduced by the fact that most conductors either melt or volatilise at comparatively low temperatures before, in fact, the temperature of white heat is attained. Iron, which is cheap and has a high resistance and which might therefore be considered a suitable substance, unfortunately melts at a comparatively low temperature. It is for this reason useless as an illuminant. It also oxidises or combines with the oxygen of the air as its temperature rises. German silver is for similar reasons not available. We are, indeed, limited among the metals to the expensive platinum or its alloys, unless we take into account the experiments which have been made with iridium, a most expensive and very scarce metal, and which, if equal to the requirements, could probably not be procured in sufficient abundance to meet the demand. Platinum is capable of being raised to a bright white heat, and can then emit light of dazzling brilliance. It has also the advantage of being practically inoxidisable. The critical temperature is, however, suddenly reached; that is to say, above a certain point, a slight increase of temperature suffices to produce liquefaction, and therefore to cause a rupture and so disconnect the circuit. It must also be remembered that the resistance of metals increases materially with an exaltation of temperature, a fact which hastens the fracture of the wire. Efforts have been made to prevent this overheating by means of automatic regulators, which short-circuit the lamp when the current reaches a certain predetermined strength, and so cuts off the current just at the moment that there is a risk of breaking the wire. Some of these are clever laboratory expedients, but nothing more. If, then, we had been restricted to metallic conductors, electric lighting by incandescence would long since have been given up as impracticable. Carbon, however, which is a non-metallic body, is a ...

od conductor of electricity, although of considerably higher ecific resistance than platinum. A very remarkable feature pertaining to it is that its resistance decreases with an increase of temperature. It is a substance which cannot by any ordinary means be ..ited or volatilised (although a temperature has been attained at which it becomes flexible), so that in this respect it is superior to platinum or any other of the metals. It however oxidises readily when heated in an atmosphere containing free oxygen, such as ordinary air. This difficulty was for a long time insurmountable, though many efforts were made to overcome it, such as placing under a glass receiver or shade, and depriving the enclosed air its oxygen by means of a piece of phosphorus, a substance which oxidises readily at ordinary temperatures. In this case, the carbon is suspended in an atmosphere of the remarkably neutral inactive gas nitrogen. But even such an arrangement as this was soon found to be clumsy, unsatisfactory, and in fact impracticable. Even supposing it to have been otherwise, the carbon procurable was very defective. Thin rods of graphite or gas-retort carbon such as is used in the Bunsen cell, or sections of the artificially prepared material such as is used in the Leclanché cell, were tried; they could not, however, be obtained of sufficiently small sectional area, and were too irregular in structure to prove practically useful. Efforts were also made, and with a better prospect of success, to accomplish the object in view, by placing the carbon in the then best obtainable vacuum. The vacua were for a very long time far from perfect, and as a consequence the durability of the carbons was very brief, but when it was shown how it was possible to secure an all but perfect vacuum, a fresh impetus was given to the idea of lighting by the incandescence of thin pencils or, as they were subsequently called, filaments of carbon. Since then, the real improvements that have been made have been in the formation and fixing of these filaments, which can now be prepared from almost any substance having a large proportion of carbon in its composition. As organic substances consist to a great extent of carbon, and as these substances can generally be decomposed somewhat readily, it is only natural that they should form the basis from which the filaments are manufactured. Filaments as they are now made, can be divided into two classes, (1) those in which the fibrous

structure of the carbonaceous body is retained, and (2) those which the original or organic structure is altogether destro during the process of manufacture, and the material rende thoroughly homogeneous. To the first class belongs the Edi lamp, and to the second class, the lamps of Swan and the majo of other inventors. It is a remarkable fact that Edison asserted his patent that to give the carbon the highest possible resistance the smallest tendency to disintegration, it should retain its stru ral character, and that such carbons alone possess these quali qualities which are impaired by any treatment tending to fill the cells or pores with unstructural carbon, or to increase the sity or alter the resistance of the fibre. Swan, on the other h maintained that the structure of the material should be ent destroyed, and the carbon filament made as dense as poss Although good and efficient lamps can be manufactured on e of these principles, experience seems to show that the latte homogeneous filament is the better of the two.

In attempting to deal more specifically with the manufactu incandescent lamps, we are met with two serious difficulties: first is due to the enormous number of processes which been introduced, but to the great majority of which the limit purpose of this work will not permit us to refer. Legal deci which have been given in recent actions between the va makers, have however considerably reduced the number variety of processes actually in use. The second difficulty a really from a kind of jealous fear, for the practical makers of l regard their methods as secrets which it is their bounden to keep religiously to themselves.

It might have been gathered from what has already been that the chief desiderata in a good lamp are, (1) that the fila shall be sealed in an airtight vacuous glass vessel; (2) that effic means shall be provided for connecting the filament with the ternal circuit; (3) that the filament shall offer considerable re ance; (4) that it shall have a small mass, so that its tempera shall be raised as much as possible by a given quantity of h (5) that it shall be durable at high temperatures in a vacuum; (6) that the lamp shall be capable of being manufactured at a cost, and of any desired dimensions of resistance. As regar

wires
being
leads,
loops,
brass

action has been of just sufficient duration, but not lasting too long, the change from the fibrous to the homogeneous state will be readily seen. It should then be placed in water, well washed and dried. The drying is best performed by stretching the thread gently in a straight line, or if too lengthy, over a series of pulleys. If the thread is left in the acid too long, the solution is carried too far and the thread weakened, so much so as not to be able to bear its own weight even in a length of a few inches. The same thing happens if the thread on being removed from the acid is placed on a plate or piece of glass, instead of being at once immersed in the water; the acid remaining in the thread completes the dissolving process and liquefaction ensues. It is possible to remove the thread from the acid too soon, the defect then being that the destruction of its fibrous character is only partly performed.

The thread having dried, it is next cut to a uniform gauge throughout, which is done by drawing it through a series of jewel dies decreasing slowly in diameter. It is then subjected to the process of 'carbonising,' or converting it into a solid carbon filament. The thread is first wound on a frame consisting of two round carbon or porcelain rods kept in position by being fixed into holes in two side-pieces. The round rods are sufficiently far apart to make each bend of the thread correspond to one filament, for it is in the process of carbonising that the filament is definitely shaped. In order to make the loop, which was at one time one of the characteristic features of the Swan filament, the thread is turned twice round one of the carbon rods in the frame before passing to the other rod. One object of this formation is to get a long filament in a comparatively small bulb. The frame having been filled, pieces of cardboard are placed on its sides or faces to prevent accidental injury to the threads, the whole being then wrapped round with paper. A number of such parcels is placed in a crucible or cast-iron box, until the vessel is nearly full. Powdered charcoal having been shaken over the contents to fill up any spaces that may have been left, the lid is placed in position, and an air-tight joint made with a little fireclay. As the powdered charcoal gets hot it absorbs any free oxygen that may be in the crucible and prevents any getting to the filaments, were it to

speedily destroy them. The crucible being thus prepared, ed in a suitable furnace and raised slowly to a white heat. gradual increase of temperature is important in determining apeliness of the filament. Too rapid an increase in temture would alter the dimensions of the frame and cause the s to sag, so that the form of the filaments would be more or istorted. The high temperature is necessary to render the hard and durable, to increase its conductivity, and to reduce pacity for holding atmospheric and other gases within its This last-mentioned feature is not only interesting, but it fraught with the utmost importance. All substances are or less porous, and have the power in varying degrees of ng gaseous particles within those pores, a power or property as occlusion. As the temperature of a body rises these es particles expand and force themselves through the sub-, frequently causing minute fissures; with some substances do not liquefy, such as carbon in its ordinary form, this of occluding gases returns with a resumption of the normal rature. It is, therefore, imperative that the nature of the should be so altered as to prevent this taking place. Hence ecessity for thorough carbonisation at a high temperature.

his alteration in character of the carbon is continued in ext process, which is that of 'flashing.' Before proceeding this process, however, the filaments are cut to about the d length, sufficient margin being allowed for making connecith the platinum wires, which pass through the bulb to the al circuit. The filament is then held by a pair of clips cted with suitable terminals, by means of which a dynamo, ter still, a battery of secondary cells, can be joined on. The nded filament is then placed in an atmosphere of some -carbon, more generally ordinary coal gas (which is rich in n), and traversed by brief currents sufficiently strong to raise portions of it, to a white heat. The effect of this process is to lly decompose the gas, which is at the ordinary atmospheric ure, and to cause a deposition of carbon particles on the surof the filament. Should there be, as is generally the case, equality in the *filament*, causing a variation in its resistance, *rtion will be raised* to a higher temperature than another,

and upon this hotter section a greater deposit of carbon will take place. The flashing process is therefore continued until the carbon assumes a uniform temperature, that is to say, until it becomes uniformly luminous throughout. The process also serves to reduce the power of occluding gases in the interstices between the particles. The filament is next placed in an exhausted receiver, and a continuous current passed through it, the result being that the carbon is hardened, the conductivity increased, and the power of occlusion eventually destroyed; but to bring about these results the temperature must be raised to a white heat the current being maintained until the resistance is reduced almost to the required limit. The final flashing may, however, be reserved until the filament is fixed in the bulb and ready for finishing off. Platinum wires are always employed in mounting the filaments as it is the only metal which has a coefficient of expansion nearly equal to that of glass; that is to say, it expands or contracts with variations of temperature at almost exactly the same rate as glass, so that it can be fused into that material without any risk of its subsequently fracturing the glass on cooling. The wires are first fused along the sides of a short piece of glass rod, or have a little molten glass twisted round them while they are held in position. In the former case, a piece of glass tubing is fused over the rod, thereby encasing the wires for a portion of their length. The connection with the carbon is made by flattening out the ends of the wires into minute plates, which are then bent gently round the ends of the filament, to which they are fixed with carbonaceous cement. The joint is completed by carbonising the cement by means of a strong current sent through it. Instead of using the cement, the joints are sometimes perfected by immersion in a hydro carbon liquid or gas, the filament being short-circuited and the joints raised to incandescence by a strong current, causing a decomposition of the hydro-carbon, and a deposition of the carbon upon the joints. There are several other methods of mounting, but they are mostly based upon or are modifications of those above described.

The next process is that for exhausting the bulb of its contained air and moisture. This has to be performed carefully, and it is here that some of the greatest difficulties are met with.

uum obtainable in an ordinary mechanical air-pump is, already indicated, far from perfect, and useless for the There are, however, two types of mercurial air-pumps so far superior to the mechanical form that they can ven higher vacua than are actually required for lamp- It is, of course, well known that if a long glass tube, hes long, sealed at one end, is filled with mercury and ed with its open the surface of contained in a ther convenient liquid metal in ill sink until its about 30 inches of the mercury n—until, in fact, icient height of left in the tube the atmospheric n the mercury It follows that the tube above the metal is a perfect va- is generally Torricellian fact first

Fig. 268.

of flexible s upper ex-

space. Consequently as each piston passes the junction of x, the air is swept out little by little until finally a very good vacuum is obtained in R. When the degree of rarefaction becomes considerable, the pistons fall smartly upon the column of mercury and give out a distinct metallic ringing sound. This hammering frequently sets up such strong vibrations as to fracture the glass and it is this which really limits the length of the shaft. As the mercury falls on the barometric column, an equal quantity is, of course, driven out at the lower end, carrying with it, also, the bubbles of air which separate the little plugs. The mercury collected in H is replaced in A as necessity arises. This process is also very long and tedious.

The exhaustion can be materially hastened by employing a good mechanical air-pump to exhaust the system as far as possible by mechanical means, the process being afterwards completed with the mercury pump. A simple barometer gauge can also be used to indicate, by the height of its contained mercury, the degree of exhaustion obtained.

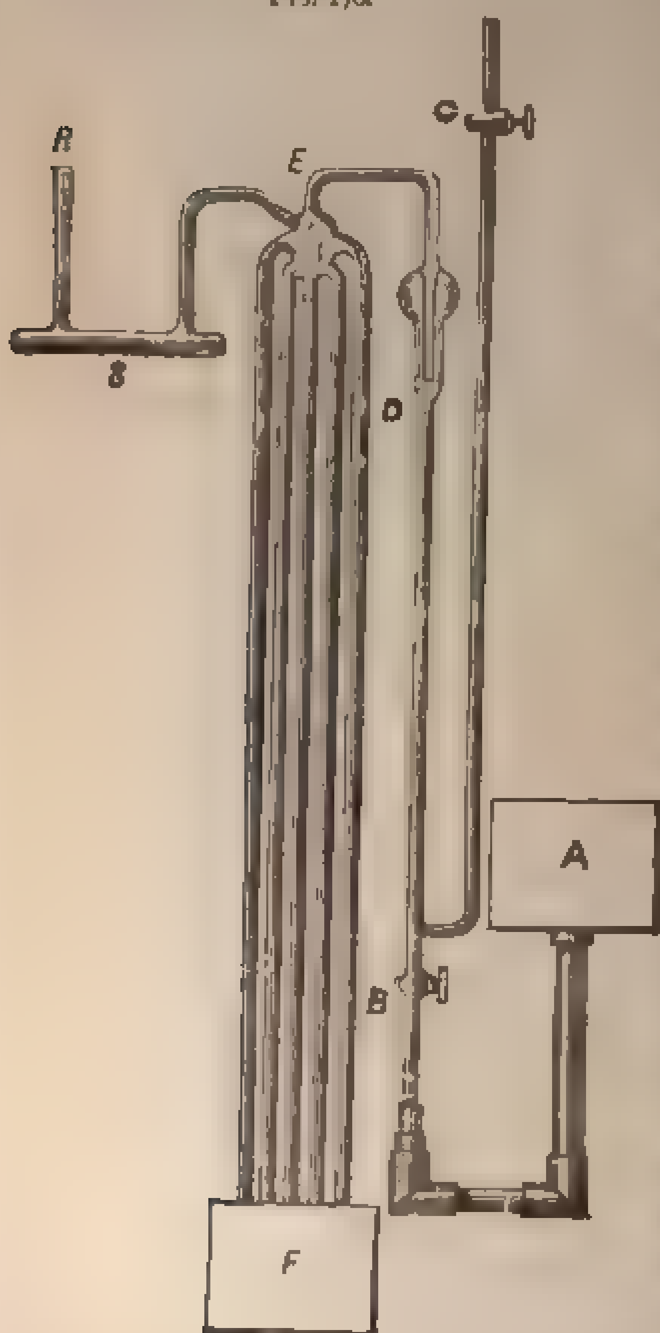
These are the two systems of pumps upon which the apparatus actually employed in exhausting incandescent lamp bulbs is based. These simple forms are, however, open to many serious objections. A film of air always attaches itself to the surface of glass, and at times some difficulty is encountered in getting rid of it. Air is also supposed to be confined in the mercury itself, but there is some doubt on this point. To get rid of other impurities the mercury should always be distilled, and never allowed to get dirty by contact with brass or any other substance which it is likely to attack. Ordinary air always contains more or less moisture, and to get rid of this the air as it is exhausted from the lamp bulb is made to pass through sulphuric acid or phosphoric anhydride in order to dry it before it is allowed to enter the pump. Grease used for lubricating taps is also injurious for similar reasons, and should, therefore, be avoided. Taps themselves are serious offenders. No matter how perfectly they are made, they must allow some air to enter the pump, more especially when high vacua are obtained, and when, therefore, the pressure of the outer air on the tap is very considerable. To overcome this difficulty, taps are now superseded in the essential parts

The other type of mercurial pump to which we have referred the Sprengel, the fundamental principle of which is illustrated fig. 269. It consists of a stout glass tube, $c\ d$, 39 or 40 inches g, with a branch x conted to the vessel R to be austed. A large funnelped reservoir, A, supported a stand, is connected to by means of a piece of ia-rubber tubing, the size the channel through it ng adjusted by means of a ch-cock. The lower end $c\ d$ dips below the surface the mercury in the flask B, ich is furnished with a out a little higher than the ttom of $c\ d$, in order to ow the mercury to pass out o the reservoir, H. The ch-cock is so adjusted as ly to allow the mercury to ss down the shaft a drop at ime. Each drop constitutes plug or piston which fits sely to the sides of the ss and in its descent drives fore it any air that may ppen to separate it from e drop beneath it. The ft $c\ d$ is to all intents and rposes a barometer, so that the drops of mercury accumulate til a column is formed about 30 inches high, the actual height pending upon the counter-pressure of the outer air at the be being. Hence the distance which the mercury pistons ultitely fall is only 9 or 10 inches It will be evident that as e drops fall, and tend to establish a vacuum above them, the in R expands and part of it occupies this otherwise vacuous

FIG. 269.

bubbles usually find their way to the surface of the glass, and slide upwards with the mercury. This fact permits the adoption of a very simple but effectual form of 'air-trap,' as shown near the top of the tube D. The tube is at this point enlarged to a bulb, through the top of which is fused the tube leading to E. This inner tube is open at its lower end, which is clear of the outer tube, so that the mercury on rising passes freely through it on its way to the pump, while the air-bubbles continue their course along the surface of the glass, and are consequently arrested or trapped in the upper part of the bulb.

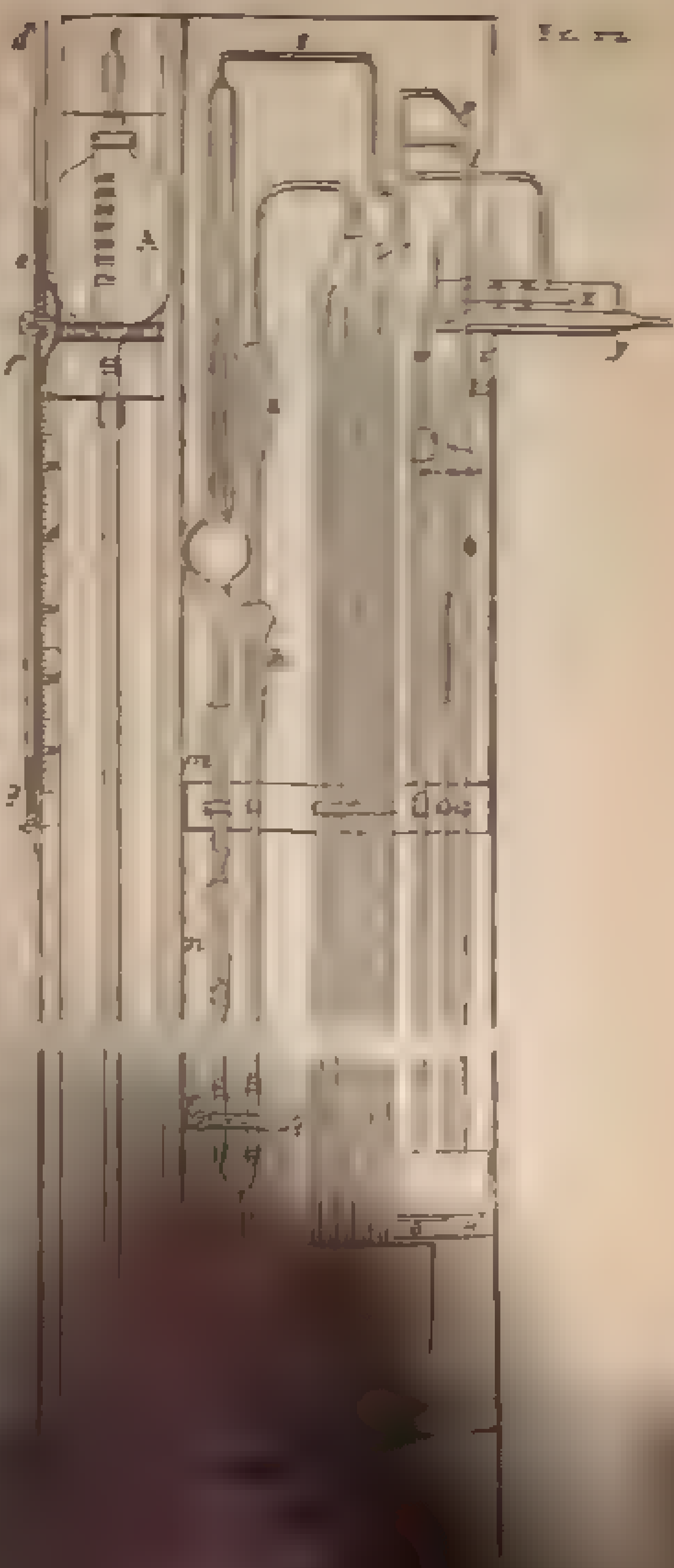
FIG. 270.



A more elaborate form of the same pump is shown in fig. 271, for which we are indebted to the Council of the Society of Arts.

The supply vessel A communicates by a long flexible tube with a forked tube *c*. The tube on the left, which is controlled by the pinch-cock *r*, leads through two air-traps, *n*, *m*, to a McLeod pressure gauge, an appliance used for measuring the pressure in very high vacua where the ordinary means of measurement are not available. The process consists in compressing a large but known

of the rare- into a com- ely small space known dimen- and then mea- the pressure the altered ions. The tube e right, con- by the pinch- leads through air-traps *h*, *i* e pump-head, the mercury s between the ll-tubes, which bout 39 inches and which dis e into the capa- reservoir shown bottom The is the exhaust having three hes, one, *s*, g to the od gauge, ano- , to the baro- gauge, *u*, and r through the and absorb- bes, *x* and *y*, lamp bulb. parison baro- s placed at ... pply vessel ... red fro... and ...



with the collecting vessel so as to allow the mercury after it has passed through the pump to refill it. In experimenting it is sometimes necessary to count the number of times this vessel is raised; this is done automatically by the tubes *de* and *fg* with the aid of a few leaden shot, one shot being made to fall from the upper to the lower tube every time the vessel A is raised. Mr. Gimingham has experimented very extensively with mercurial pumps, and finds that 39 inches is the best length for the fall-tube. He says that 'An experiment recorded in my note-book with a five fall tube pump whose tubes were at first made 33 inches long, and then were lengthened to 39 inches by sealing pieces to their lower ends, shows that by passing the same quantity of mercury through at the same rate, a certain globe was exhausted in the first case to 50 mm. pressure, and in the second to 1 mm., showing a great increase in the rate of exhaustion, due to the extra 6 inches of fall-tube. On the other hand, if they be made of a greater length than 39 inches the fall of the mercury at the high exhaustion causes such severe hammering that the tubes are liable to be fractured.'

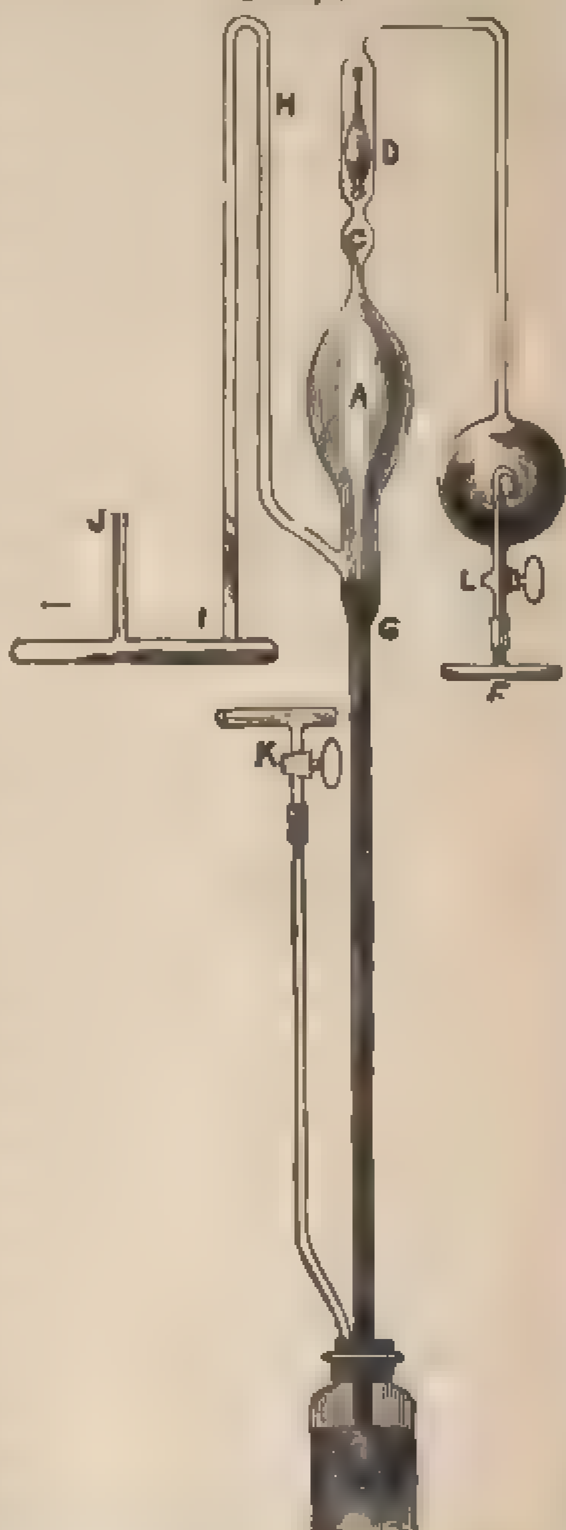
From other experiments he deduced that in the higher stages of the exhaustion, the air particles, instead of being swept out by the pistons, are taken out by a process of entanglement with the mercury.

Mr. Swinburne has invented an exceedingly simple and useful pump (fig. 272). It consists of a bulb, A, on a long shaft, G, which passes through an air-tight stopper nearly to the bottom of the bottle B. The bulb is drawn to a point at the top, and the tube is enlarged into a little bulb at C. It is again contracted where it joins the valve tube D. From the top of D there is a tube to the globe E communicating with the tube F, which serves for a number of pumps and in which a vacuum is maintained by a mechanical pump. H leads to the drying tube I, and J to the branch tube on which the lamps are sealed. The pump is started by opening the tap L, but the bent tube leading into the globe E is drawn very fine so that the exhaustion takes place gradually. The bending in this tube prevents any globules of mercury that may be drawn over into E from getting into the vacuum tube F. When the vacuum in the pump and lamps has been brought to about half an inch, communication with F is cut off by turning the

, and the tap K is opened, and a higher vacuum developed bjecting the mercury in B to alternations of ordinary atmo-fic, and high air pressure.

height of the mercury n in the shaft G is that to the ordinary atmo-ric pressure in B, so that the high-pressure air ends through K, the mer- is driven past the open-f the tube H, through the or pump-head A, through d half way up the tube D. extra pressure being now wed from B, the mercury ends, the valve in D closing opening into C before it ll fallen so that the valve led by the mercury. The ury continues to fall till ches the level G, whence ther exhaustion by expan-from the lamp bulbs takes e. This small quantity of in its turn expelled, and Geissler action continued the necessary degree of ustion has been obtained. little bulb C is introduced event the mercury rising hitting the valve smartly the exhaustion ap-ches completion. Were owed to do so the air d probably be driven st the side of the glass stick there. It will be

Fig. 272.



nt that, as the passages both above and below D are exhausted, small pressure will suffice to raise the valve.

Reverting to fig. 269, it will be apparent that if the atmospheric pressure in B is reduced the mercury column in the shaft *c d* will be shortened, whence a shorter shaft will suffice. In pumps of this pattern recently devised by Mr. Stearn, there are the fall tubes, each 10 inches long, completely enclosed in a partially exhausted chamber.

Such pumps are finding considerable favour, but they introduce a further risk, for, if anything happens to interfere with the partial vacuum, the mercury will be driven up with considerable force and get into the upper parts of the pump, possibly breaking it.

Many suggestions have been made to heat portions of the mercury pump with a view to hastening its action, and pumps have been constructed to suit this purpose, but they do not seem to have met with much success in practice. Vacua can now be obtained far in advance of the actual requirements, the most perfect vacua being developed by the absorption of the residual gas after the exhaustion has been pushed as far as possible by the mercury pump. This is done either mechanically or by using some substance with which the air particles combine chemically. Dewar has produced a vacuum, which he estimates at [illegible] of a millimetre, by heating charcoal to redness in the vessel exhausted by the Sprengel pump.

Mr. W. Crookes says he has obtained a vacuum of one-hundredth of a millionth of an atmosphere, which is equivalent to one-[illegible] of an inch at the top of a barometer tube 200 miles in height. That would appear to be an almost perfect vacuum, but such is the smallness of the molecules of matter, that, were a small tube containing a centimetre of air exhausted to that extent, there would still be left in it ten billion molecules.

Although it is, evidently, a comparatively simple matter to obtain the degree of exhaustion necessary for incandescent lamps, there are several causes for a deterioration manifesting itself in the vacuum after the finished lamp has been laid aside for a time, such as the occlusion of gases by the carbon and platinum, and by the cement employed to connect them together, and the very thin film of air which is liable to adhere to the inner surface of the bulb. In order to expel these gases, the filament is raised to

ndescence during the later stages in the process of exhaustion, he heat is applied externally.

The lamp having been sufficiently exhausted, the small glass e connecting the bulb to the exhaust tube is fused, drawn out thread, and the lamp sealed off.

It remains now to test its efficiency, that is to say, the amount ight emitted for a given electrical power. A lamp may be to have a very good efficiency if it yields one candle power eturn for 3·5 watts, so that an average 16 candle power lamp uld absorb 56 watts.

The vacuum is usually tested by means of an induction coil; method is to fuse two platinum wires into a glass tube leading he lamp, and simultaneously exhausted with it, and to connect e wires to the terminals of the secondary coil. The distance ween the ends of the platinum wires inside the tube is so sted that when the required degree of exhaustion is attained, spark passes through the air outside the tube, in preference to ersing the vacuous space between the platinum points An- er method applicable to the finished lamp is to connect one of the secondary to the filament, and the other to a loop nd outside the bulb, the quality of the vacuum being deter- ed by the relative feebleness of the discharge which takes e between the filament and the bulb. It should be observed , in a badly exhausted lamp, not only does the filament 'burn,' is oxidise, but it also requires a greater amount of heat to e and maintain its temperature at the required point, owing to fact that the air particles carry a portion of the heat away by vection.

The 'life' of an incandescent lamp or the number of hours it can maintain illumination varies considerably. Some fila- nts fracture in a few hours, while others will last for years, and have seen one which had been burning steadily for at least o hours, and at a good efficiency. It will be obvious that life of the filament must in a great measure depend upon the ngth of the current which is sent through it. If a compara- ly feeble current is employed the lamp will last much longer n it would with an abnormally powerful one. On the other d, the luminosity increases much more rapidly than the current

strength, so that the question really resolves itself into one of comparative expense. A lamp that is burning low yields a much lower efficiency, but lasts longer, than one of the same type which is brilliantly illuminated ; but it may be accepted, generally, that it is more economical to run lamps at a high than at a low efficiency.

The filament of the Edison lamp, extensively employed in America, is made from bamboo, which is carefully cut into very fine strips of the required length, provided with little enlargements at the extremities to facilitate the fixing to the platinum wires which are fused through the bulb.

The carbonising and subsequent processes are similar in principle to those already described, the method of fixing the carbon to the platinum being, however, somewhat different. The flat ends of the carbon are mechanically gripped by the platinum, and the junction is made electrically perfect by a small coating of copper deposited electrolytically,—that is to say, the joint is connected to the negative pole of a battery and is then placed in a bath or vessel containing a solution of copper sulphate, in which is immersed a copper plate connected to the positive pole of the battery. As the current passes through the solution, copper particles are dissolved off the copper plate, and an equal number of particles precipitated upon the joint. Electrical continuity is in this way ensured, but during the subsequent working of the lamp there is a tendency towards the disintegration of the copper, which is sometimes deposited upon the inner surface of the bulb as a thin metallic film.

Such are the general features pertaining to the construction of the Swan and Edison lamps; but the commercial interests of both have been amalgamated, and the distinction between them is therefore less marked than formerly, the Edison lamp pure and simple being now obsolete in England.

For ordinary purposes the filaments of the Edison-Swan lamps are shaped either as single or double loops. There are, however, several ways in which connection is made between the lamp and the external circuit, involving a corresponding variety in the form of the lamp holders.

Figs. 273 to 275 illustrate the methods more generally employed for connecting the filament to the external circuit. In

lamps, fig. 273, the [illegible]
[illegible]ply bent into [illegible]
[illegible]ed with two spiral springs [illegible]
[illegible]ee ends of the [illegible]
[illegible]oulder of the lamp [illegible]

Fig. 273.

[illegible] Just [illegible]
[illegible]
[illegible] 274 [illegible]
[illegible], the [illegible]
[illegible]

nected to the two brass segments embedded in the cement. The collar has two small pins, which fit into the 'bayonet joint' holder, which is shown in the figure, with its two parts separate. In twisting the lamp into the holder the segments make rubbing contact with the two spiral springs, which project a little from the guiding tubes. These spirals are connected to the circuit leads, and the lamp is thus thrown into circuit, by the mere act of fixing it in the holder.

Fig. 275

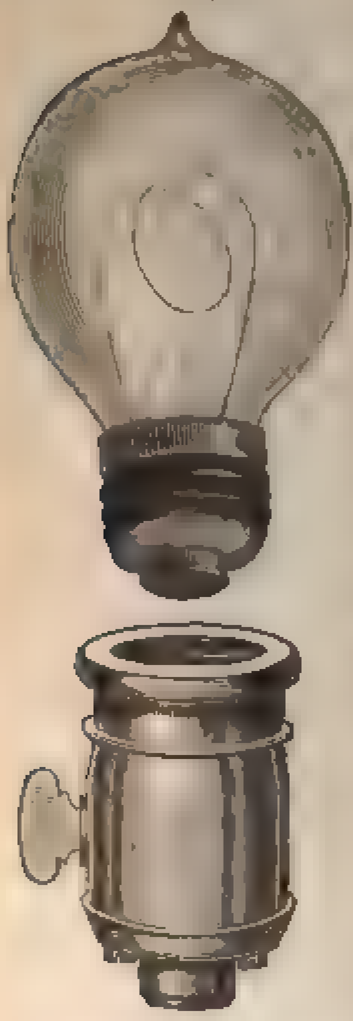


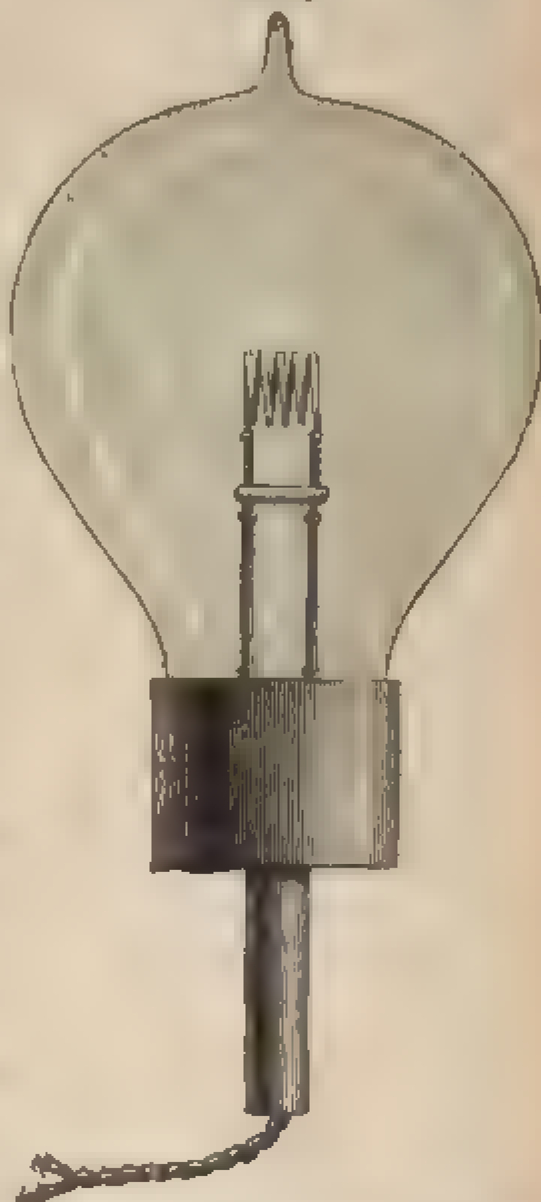
Fig. 275 illustrates the connection known as the Edison screw, in which one end of the filament is connected to the coarse screw thread, and the other to the insulated brass stud projecting from the bottom of the lamp. This affords another means of throwing the lamp in circuit by the act of placing it in its holder, which is provided with a corresponding brass screw thread, and a small brass disc mounted on a spring, which maintains contact with the stud on the lamp.

Lamp-holders are sometimes provided with small switches for making and breaking the lamp circuit, the switch action being generally controlled by a tap handle similar to those used for gas-burners. In the Edison socket, as made by the Wassall Electric Co. (fig. 275), the tap carries a cam, which works against the curved edge of a brass strip, causing a to-and-fro movement of the spindle which, in the position for lighting, presses a brass spring against the stud on the bottom of the lamp. It releases with a snap action. Lamp switches are, however, more generally independent, and fixed in convenient positions on the wall, &c., and one or two forms of them will be described in the following chapter.

Fig. 276 illustrates a form of lamp designed to overcome a difficulty experienced hitherto when using incandescent lamps

for optical lanterns, as well as in other cases where the source of light should be small and approximate as nearly as possible to a point. The shape of the filament is that of a flattened spiral, forming a square grating constructed so that when fully incandescent it produces a square of intense luminosity, the light from which is wholly gathered up by a condensing lens in the focus of which the lamp is placed, and gives a perfectly uniform disc of light. This would not be the case if an ordinary incandescent lamp were used.

FIG. 276.



The lamp is mounted in a brass collar, with a shank to it, through which passes a flexible cord for leading the current to the lamp. A convenient holder is also made for the shank to fit into. It is provided with a set screw, by means of which the lamp may be varied in height or turned round; the holder is made with screw holes for screwing on to a block, or it may be soldered to the metal bottom of the lantern.

The lamp is made in two sizes (*a*) 35 to 55 volts, giving about 50 c. p. (*b*) 80 to 100 volts, giving about 100 c. p.

Incandescent lamps of the ordinary type are also made of high illuminating power, equal to that of 200, 500, and 1,000 candles. These lamps are suitable for interior lighting in public buildings and factories, and in other situations where a powerful and steady light is required.

In proportion to their actual c. p., these lamps are more economical to instal than groups of small incandescent lamps;

for example the 200 c. p. lamp gives a light equal to 12 or 13 lamps of 16 c. p., but costs only twice as much as a 16 c. p. lamp, although the expenditure of energy per candle-power is in each case about the same.

These high c. p. lamps are fitted with strong brass terminals, and a special form of holder, which supports the lamp at the neck, takes the strain off the terminals, and can be readily adapted to any form of fitting, being provided with a screw thread of standard pitch—usually 1 inch male gas thread.

The following table supplied by the makers is interesting as showing the approximate E.M.F. and current required for the various classes of Edison Swan lamps :

1	candle-power	from about	3	volts &	·8	amperes	to about	8 volts	&	·3 amp. to
2½	"	"	5	"	1·4	"	"	25	"	·45 "
5	"	"	5	"	3	"	"	65	"	[illegible] "
8	"	"	10	"	2·8	"	"	120	"	·3 "
16	"	"	15	"	3·7	"	"	160	"	·4 "
25	"	"	40	"	2·2	"	"	123	"	·7 "
32	"	"	50	"	2·4	"	"	120	"	·8 "
50	"	"	50	"	3·5	"	"	125	"	1·4
100	"	"	50	"	7	"	"	120	"	2·7 "
Micro and Miniature Lamps		"	3	"	·8	"	"	8	"	·3 "

All lamps taking less than ·9 ampere are marked at 4 watts per candle, and all lamps taking more than ·9 ampere at 3·5 watts per candle. It is of course optional for consumers to run the lamps at higher efficiencies, if under the circumstances they consider that the higher efficiency compensates for the shorter life. Assuming an efficiency of 3·5 watts per candle, it follows that 746 watts, or one electrical horse-power, expended in the filaments would produce a light of 213 candle power, an equivalent to that of thirteen 16 candle power lamps. But the power developed by the dynamo is frittered down by the resistance of the leads, &c., so that in practice, not more than ten 16 candle-power lamps can be maintained per horse-power generated.

Lamps are sometimes silvered over one half of the bulb when the light is required to be reflected in one direction instead of being distributed all round. But in this case, the plane of the filament should always be placed in a line with the object it is

sought to illuminate, as the light obtained from the lamp is always greater in that direction than in the direction at right angles to the plane of the filament. Artistic effect is also sought by colouring the bulbs to suit the surroundings, although this involves a loss of light, as certain of the rays are absorbed by the glass, the actual percentage so lost being governed by the particular colour employed. This absorption is altogether independent of the loss caused by the density or opacity of the material.

The Edison-Swan lamps are as a rule only made for parallel working, that is to say, they are all joined across the same pair of leads or mains, so that the current from the dynamo or other source divides between the various filaments. Of course it is possible to join two or more lamps in series, but under such circumstances the fracture of the filament in one lamp involves the extinguishing of the other lamp or lamps in series with it. If, therefore, all the lamps in a circuit were joined in series, the failure of one lamp would result in a total disconnection of the circuit. The parallel system has many advantages. There is no risk of receiving a serious shock on touching the mains, as the total potential difference is only that necessary for one lamp, which rarely exceeds 100 volts or thereabouts. If one of the branch leads should become broken, only the lamp on that branch will be thrown out of use. The means available for connecting the lamp to the supply wires are of the simplest description. The insulation of the mains is a matter of less difficulty than with high potential circuits.

On the other hand, the cost of the mains in a large installation is very considerable, for large conductors must be employed, otherwise their resistance would be so high as to cause a serious waste of electrical energy in overcoming that resistance. It needs also to be added that the maintenance of a constant potential difference throughout an extensive network of wires is a matter of some difficulty, a difficulty which does not attend series working.

The best lamp yet constructed for series or constant current working is probably that of Mr. Alexander Bernstein. The filament is composed of a slender carbon tube, made by carbonising a silk braid of fine texture, and it is remarkable that the fine threads composing the braid are distinctly discernible in the

finished filament. Fig. 277 illustrates the construction of the lamp in which the straight carbon tube or filament *a* is supported by pieces of iron wire *b b*, their lower extremities being connected to the short pieces of platinum fused through the bottom of the bulb. These wires, *b b*, are bent in such shape as to almost touch each other at *c*. They are also furnished with sleeves of insulating material *d d*, connected together by a spiral spring *e* which strives to draw them together. As long as the carbon is intact, its rigidity prevents contact between *b* and b_1 at *c*, but as soon as a flaw in the carbon appears the current commences to destroy it, and the spring *e* gradually draws the wires together, until a perfect contact is produced at *c*, and then a short circuit is obtained inside the lamp. It will thus be seen that this is an excellent device for series working, for on the extinction of one lamp by the fracture of its carbon, the circuit for the other lamps is automatically completed.

Fig. 277

In a form of lamp now being introduced the spiral spring is dispensed with, a portion of one of the iron wires being hammered out flat, and a slight springiness imparted to it so that on the carbon being broken continuity is established at *c*.

The manufacture of the bulbs for 'loop' lamps is comparatively a simple matter, but with lamps having a rigid rod or tube such as the Bernstein, the case is very different. This will be evident when it is observed that the length of the carbon is considerably greater than the diameter of the neck of the bulb; with the ordinary bulb, the insertion of the mounted carbon would be a matter of impossibility.

The method of making the Bernstein bulb is very ingenious. Two bulbs, *c*, *d* (fig. 278), are first blown in a piece of glass tubing *b c*; the end *b* is then broken off, and the bulb *c* being heated it is worked into the form of an open cylinder. The carbon and the connecting wires, fixed in a glass stem, are then introduced through the large opening thus made, this opening being then closed so that

only one bulb remains. The next operation is to weld a piece of small tubing to the top of this bulb, after which the small tube *c* at the bottom is broken off, and the stem with its connecting wires dropped through and fused into position. The next performance is to exhaust the lamp by way of the little tube fused on to the top, and that being completed, the bulb is sealed off and fixed into its socket.

FIG. 278.

In order to prevent the interruption of the circuit by the removal of a lamp, its holder is constructed in such a way that the lamp can only be withdrawn from it if a short circuit has been made in the holder beforehand, and, furthermore, as this short circuit can only be broken after the lamp has been placed in position, it is not possible to disconnect the circuit at the holder.

This holder is shown full size in figs. 279 and 280. A plate of insulating material, *h*, serves for the support of two metal sleeves, *i* and *i*¹, which are made suitable for the reception of the two square pins, *g* and *g*¹, of the lamp cap (*fig.* 277). For the purpose of obtaining a good contact between the pins and the sleeves, the outward side of each of the latter is cut away and replaced by two flat springs, *k* and *k*¹. The conducting wires are attached to the lower ends of the sleeves. The S-shaped piece, *m*, which can be turned by means of an external handle, serves the purpose of making a short circuit in the holder.

FIG. 279.

In fig. 279 the position of short circuit is indicated. For the purpose of obtaining a good contact between the piece *m* and the metal sleeves *i* and *i*¹, the latter are provided with two other flat springs, of which the one on the left side, near *k*, is bent at right angles at its lower end. The spring near *k*¹ carries at its lower end a square pin, which prevents the turning of the piece *m* in the other

. On the other hand, they consume a practically
of energy, for the light cannot be turned down
luction of a shunt, or of resistance, in which the
uld otherwise be developed in the lamp is ex-
e, however, bad for street lighting unless of high
most of the advantages which pertain to them
house, disappear when they are taken into the
lic look for a brilliant light and get only the
good gas jet, and have to pay dearly for the
exceedingly adaptable to the lighting of railway
now no equal for ship-lighting, their usual com-
ses being bad oil and worse lamps. In the case
ners expense is not of paramount importance;
be wondered at that in this work incandescent
ow reigns supreme. Incandescent lamps should
le service in mines and in the bunkers of ships,
fficulties to be contended with are want of porta-
of sparking between the broken ends of a wire or

These are trifling matters which must soon be
here is but little doubt, that before long the
ie 'safety' lamps will be relegated to historical
is a scope for incandescent lamps for the use
many surgical examinations and operations, as
croscope and the optical lantern.

stimate the amount of light emitted by any lamp,
ric or otherwise, a large number of 'photometers'
rs have been devised, but excellent as some of
theory, they have, when applied practically, ...

Measurement of every kind requires some ...
h which to compare the substance or force ...
ure; and it ... [illegible]
be fixed ... [illegible]
be ... [illegible] The majority of ...
[illegible]

burn 120 grains of spermaceti wax per hour. The length of t candle varies slightly with different makers, ranging from 8½ t inches measured from the shoulder, where the diameter is th 0·8 in., the diameter at the bottom increasing to 0·85 or 0·9 in.

In practical work a straight candle is selected and cut into equal parts, which are subsequently used together on a short placed at right angles with the scale-bar of the photometer. T two flames give a more reliable, or better average result, th single one. Candles are lighted ten minutes before the com-mencement of testing so as to allow them to arrive at their nor rate of burning, which is shown when the wicks are slightly over and the tips glowing. In fixing them in position the pl of curvature of one wick should be at right angles to the pl of curvature of the other. If the candles are used when wicks are straight or when a little knob or rose of carbon thread has formed at the tip, the tests will give erroneous res

The special requirements of a standard flame are that combustible must be of known and definite composition; conditions of burning must be of a simple and definable char and the nature of the combustible, as well as the conditio burning, must be such that atmospheric changes may prod minimum effect upon the light.

Now white spermaceti has a melting point of 109°, but a quantity (varying from four to five per cent.) of beeswax with a me point of 140° is usually added in order to prevent the crystallis of the spermaceti. The spermaceti itself is not a definite che substance, its constituents varying considerably, whence it fa answer the first requirement, for the consequence of the differe in the proportions of the natural and added constituents small variations are found to occur in the melting point.

The number and size of the threads in the wick, its che treatment, the closeness of the plaiting of the strands, and degree of tightness with which the wick is stretched, are conditions which affect the light of a sperm candle, yet are all left undefined by the Acts of Parliament; and, in prac manufacturers differ in regard to them.

Even were the candles made as exactly alike as possible are other conditions of variation which cannot be eliminated.

the light varies from moment to moment as the wick er, as the knob at the end of the wick accumulates or ay, and as the cup fills or empties itself of melted sperm. mber of experiments made by a committee appointed by d of Trade showed that while the candles from a single ve fairly concordant results, the average obtained by ten nts with one packet differed as much as 15 per cent. from ge obtained by ten experiments with another packet. In minations a maximum variation was found between two candles of 22·7 per cent. in illuminating power. All periments were made by one observer, working with one and in the most uniform manner possible.

method of taking the average of three consecutive candle ations does not therefore serve to eliminate the errors of le standard, for the candles employed may be taken from containing candles of a uniformly high or a uniformly low ing power.

lard candles are greatly affected by slight differences of t, so that a candle which gives a certain amount of light ands of one operator, may give a widely different result d by a second operator.

xtreme sensitiveness of standard candles to differences in t is shown by the following typical experiment. Four as examiners tested on the same day a specially stored f coal gas. They used the same photometer, and candles packet selected for the uniformity of the candles con- it. The mean of two closely agreeing testings by one gave the illuminating power of the coal gas as 16·5 can- le the mean of two closely agreeing testings by another illuminating power of the coal gas as 19 candles.

. W. Dibdin has reported very adversely upon the stan- dle. He found on one day that the average of the tests dles made by one firm (A) showed the illuminating a certain gas flame to be equal to 15·8 candles, while manufactured by another firm (B) gave a value of 14·9 on another day candles A gave a value of 14·8 to a con- flame; while candles B gave a value of only 12·9.

therefore be readily conceived that a total variation of

10 per cent. is almost a normal result, while far greater d
are of common occurrence.

Another cause of unreliability under certain condition
when the temperature of the testing room rises above th
the candles invariably give discordant results, sometimes
over 25 per cent more than the known value of the co
flame. The principal cause of variation is, however, th
form and variable structure of the wick, which at one
eighteen threads in each of its three strands, while at
sent time the number has increased to twenty-one and twe
Various improvements have been effected in the proc
'drying' the spermaceti, or freeing it from oil, and the d
maceti now manufactured seems to require a wick contain
threads of cotton to raise it in the melted form and cause
bustion at the required rate of 120 grains per hour. Bu
with thick wicks give less light than those whose wicks are
Thus the effect of the improvement in the manufacture of sp
has been that standard candles give less light now than they
years ago, and probably still less than they gave at an ear
when the average consumption of candles of six to the po
140 grains per hour.

A further very apparent objection is that the illuminati
is subject to fluctuations from minute to minute, owing
tions in the length and form of the wick, and to the fil
emptying of the cup of the candle, according to the mo
of the surrounding air.

Sufficient has been said to make manifest the impe
of the spermaceti candle as a standard.

One of the sources of error, viz., the irregular consum
the spermaceti, can be to some extent allowed for by weig
candle before and after the tests are made, the time of burn
also noted. If the consumption has not been at the exac
120 grains per hour, the light emitted should be deemed
tionately different in intensity, and the measured intensit
light as observed by the photometer, should be acc
increased or diminished in the same proportion by a sin
of three calculation. Thus if a lamp has been measured
apparatus as giving a light of 17·6 candles, but the cand

plate, having a small vertical slot of such dimensions as to of the passage of just as much light as equals that afforde two average standard sp candles, when the gas sumed is sufficient to yi flame three inches in he It will be seen from the fi that a glass chimney is ployed ; it measures 6 inc high by 2 inches in diame the supply of gas neces to produce the required fla being controlled by a tap, in the better class of instr ment by a micrometer co capable of very fine adjust ment. The two horizont wires attached to the back of the screen, one on either side of the chimney, are placed at the requisite distance above the burner, and serve the purpose of determining when the prescribed flame length has been obtained. The apparatus is sometimes used with the richer pentane vapour as the illuminant (reference to which will be made presently). In such cases a second silver plate and slot is provided of reduced dimensions, and furnished with a pair of horizontal wires $2\frac{1}{2}$ inches above the burner, to which height the flame must be adjusted.

The Methven screen has the advantage that it forms a reliable and practical standard, easy to manipulate and not likely to get

of order. Its simplicity of construction as well as of manipu-tion is self-evident, and its suitability for the required object has en demonstrated by Mr. F. W. Hartley, who made a number of ngthy series of tests with the apparatus, using slots of various mensions. In one set of tests he found that with a 5 cubic feet r hour flame, of common coal gas of 14·02 candle-power, the fference in the photometric readings between a 3-inch Argand me from the same gas and from cannel gas of 35·37 candle ower, was only 0·7 per cent. These experiments tend to show at it is rather the height of the flame than the quality of the gas nsumed which determines the luminosity, and this is a most portant point, for it renders the standard virtually independent any ordinary variations in the composition and lighting pro-rties of the gas. A series of experiments was next made with andard candles which were employed to measure the light mitted by the common gas; the readings ranged from 13·24 to ·588 candle-power, showing a difference of 1·348 candles, or ·11 per cent. As these tests were made with gas supplied from e same holder, the result simply re-proves the utter unreliability the standard candle. On the other hand, when the Methven reen was employed, the two kinds of gas being consumed in rn, the extreme difference was 0·83 per cent., and the mean fference 0·3 per cent. only.

While it is of course necessary that the height of the flame ould be carefully adjusted, it is an important feature that the read-gs are not perceptibly affected by a variation of about one tenth an inch on either side of the prescribed height. The top of e flame should be as regular as possible, the burner of the best anufacture, and the chimney and screen scrupulously clean. As, owever, it rarely happens that the top of the flame is absolutely gular, it is usual to so adjust the height that the extreme points ex-nd about one-eighth of an inch above the horizontal wires. There one other precaution, and that is, that the instrument should be lowed to get 'hot,' so as to arrive at the normal condition, before y reading is taken on the photometer. If this is neglected, roneous results are almost inevitable, as the proportion of energy sorbed in heating the apparatus will be a varying quantity.

[illegible] a delay of about five minutes [illegible]

[illegible] that a standard [illegible] its indications, [illegible] should have found [illegible] where it is almost [illegible] To put the [illegible] a few words, it is a [illegible] As Parliament has not yet pre[illegible] manufacturers of [illegible] are not like [illegible] Mr. [illegible] says [illegible] the Methven flame is a matte[illegible] to variations of reading [illegible] operator.' Granting, howe[illegible] properly adjusting th[illegible] and the Methven st[illegible] more than any other from careless [illegible] when dealing with the [illegible] of the height of the fla[illegible] He also urges that the employm[illegible] is a serious disadvantage, as [illegible] acts as a lens, and [illegible] is, however, hardly [illegible] involved is so very sm[illegible] plane surface.

[illegible] Mr. A. Vernon Harco[illegible] pentane standard, the combust[illegible] with that portion of [illegible] repeated rectifications, distils at a [illegible] C. This liquid consists almost [illegible] gravity at 15° C. ranging from o[illegible]

[illegible] Mr. Harcourt draws into the [illegible] chosen according to the [illegible] corrected for pressure, temperature, an[illegible] ; then the corresponding proportion [illegible] the gasholder from a measuring flask [illegible] and the [illegible]

bic foot of air to three cubic inches of pentane, measured as liquid at or near 60° Fahr.; or, measuring both as gases, 93 of air to 7 of pentane.

When the pentane is poured upon the water in the gasholder, about thrice its vapour-volume of air above, it vaporises quickly and completely. A few minutes are sufficient for the vaporisation of the liquid, and a few hours suffice for perfect diffusion.

The opening in the burner has a diameter of a quarter of an inch, and is at the top of a cylindrical tube one inch in diameter and inches long, the thickness of the disc forming the mouthpiece at the top of the tube being half an inch. With a burner of these dimensions the mixture of air and pentane gas yields its light with a flame 2½ inches in height, when the rate of consumption is 0·5 cubic foot per hour.

The adjustment of the pentane flame to give the unit light, equal to the mean of a long series of tests with standard candles, is based upon the observations either of its height or of its consumption, and may be effected either by adjusting the height of the flame till the tip of it touches, without passing, a horizontal platinum wire stretched over the burner at the proper height, or by adjusting the rate at which the pentane gas is passing through a delicate meter. Experience of the two modes of adjustment has shown that it is both easier and more accurate to rely on the setting of the height of the flame, and to use the rate of consumption as a control only, without taking it into account in calculating the illuminative value of the gas tested.

No material variation in the light given by the standard occurs when, the height of the flame having been adjusted to 2½ inches, the observed rate of consumption does not exceed 0·52 or fall short of 0·48 cubic foot per hour. ... the rate only varies within the narrow limits of ... A series of experiments performed to ascertain the effect of changes in the proportion of air and pentane ... a variation of 7 per cent. in the ratio of air to ... per cent. in the rate at which ... meter to maintain a ... 0·03 candle in the ...

native value assigned to the gas tested by comparison with it. But an error of even half this amount is rarely obtained in the actual preparation of pentane gas.

It is remarkable that only in 37 out of 468 testings, does the result of one testing differ from the mean result of the set of which it forms a part, by as much as 0·2 candle.

Tests were made with a variable height of flame, and the averages of ten observations made at the rate of one a minute, showed that with

Height of flame in inches . .	$2\frac{14}{32}$	$2\frac{1}{2}$	$2\frac{17}{32}$
The corresponding illuminating power was	99·25	100	100·75

Other experiments demonstrated that the illuminating power of the air-gas is but little affected by variations in the temperature of the room.

Mr. Dibdin is favourably impressed with the pentane standard, and in a report to the Board of Works, he recommended its early adoption.

Similarly the British Association Committee considered it to be reliable and convenient, fulfilling the conditions required in a standard of light, and they likewise urge the rejection of the Parliamentary candle as a standard of light, and the adoption of the pentane standard.

Mr. Harcourt has designed two or three portable pentane lamps, the latest and most convenient being that shown in fig. 283. In this case a wick is used, fitting loosely and moving freely within a tube which conducts heat downwards from the flame above, so as to give rise by evaporation to a quantity of pentane vapour sufficient to feed the flame, without the top of the wick being ever exposed to a temperature as high as that of boiling water.

The lamp (fig. 283) consists of a glass reservoir, with tubulure and stopper, of the form and size of a spirit lamp, mounted on a metal stand which rests on three levelling screws. The wick can be turned up and down in the usual manner by means of a double-toothed wheel, the spindle of which fits air-tight into the tube which supports it. The lower end of the wick (which is round and rather less than $\frac{1}{4}$ inch diameter) lies in the reservoir; the upper

end is in a brass tube, about five inches in length, in which it can move up and down freely. The upper part of the tube is surrounded by a wider tube, about four inches in length and one inch in diameter; and the two tubes being joined together above and below by flat plates constitute the burner of the lamp. Around the burner is another cylinder open at both ends, of about two inches diameter, surmounted at the level of the top of the burner by a conical piece, terminating in a short tube whose diameter and length are about ¾ of an inch. Over this outer casing is a similar piece inverted, with the smaller tube below and the larger above. This second piece is connected with the first, the two being attached by two semicircular bands, so that the ends of the smaller tubes may be set at different distances apart, according to the amount of light which it is desired to obtain from the lamp. Through opposite sides of the upper tube, and above the ends of the connecting bands, are cut two narrow slots about ⅛ of an inch in width, and ½ an inch in height. These are placed at such a height that whenever the tip of the flame is visible between them the light emitted is definite and constant. The adjustment of the light, which may be set at either half a candle, one candle, or a candle and a half, is effected by means of cylindrical brass blocks whose length has

FIG. 283.

been very carefully adjusted once for all. One of these blocks is placed upon the lower tube, and the upper tube is lowered until it presses gently against the block; the screws which fix the connecting bands are then tightened, and the block is withdrawn. Since the blocks are made of the same diameter as the tubes between which they are placed, they serve for setting these tubes truly on the same axis, as well as at the right interval apart.

The point, or rather the horizontal ring, from the nearest point of which measurements are to be made when the flame of the lamp is used as a photometric standard, is midway between the tubes which surround the flame, and at a distance of half the radius of these tubes from their axis, which is also the axis of the flame. This position is defined to the eye by giving to the curved connecting bands half the width of the tubes. The zero of the photometric scale lies in the plane which passes through the edges, on either side, of the connecting bands. To mark this plane by a solid surface, a rectangular strip of brass is provided, which can be fitted on one side into the centre of the edges of the connecting bands. A small plumb-line is also provided, by means of which the lamp can be set truly vertical, and a small mirror by means of which the photometrist can observe without changing his position whether the top of the flame is between the slots in the side of the chimney. The tests to which the lamp has been subjected demonstrate that it is fractionally less efficient than the pentane standard.

The 'battle of the standards,' as already mentioned, is confined to the types invented by Mr. Methven and Mr. Harcourt respectively. It is possible that the latter is slightly more accurate than the other, but it is less convenient, and is for that reason very rarely adopted in practice, while the Methven screen is very extensively used by gas as well as electrical engineers. The Methven screen is always ready, and measurements can be taken within a very few minutes of lighting the gas. On the other hand, the amount of heat evolved by the pentane flame is so small that a considerable time elapses before the burner has assumed its maximum temperature, or attained the normal rate of burning. Careful manipulation and experience are necessary in the process of manufacturing the pentane, an operation which of course

takes time to perform, and which would therefore frequently preclude its use.

Under the circumstances it is perhaps as well that our laws change but slowly, and that the legal substitute for the universally condemned sperm candle has not yet been determined.

Supposing an absolutely reliable and permanent unit of luminosity to be available, we are still confronted by the second difficulty, viz., the want of a means of accurate measurement. Practical photometers are one and all simple comparison instruments, the light emitted by the standard and the source under test being compared simultaneously, and these comparisons must perforce be made by the eye. Unfortunately that organ is an untrustworthy piece of scientific apparatus and incapable of accurate discrimination. Its sensitiveness also varies considerably with the individual, so that the whole of any series of tests should be taken by the same experimenter, although even then there is some risk of personal error. Of course this difficulty is in some measure overcome by continued practice and attention.

All practical photometers are based upon the fundamental law that the intensity of illumination on a given surface varies inversely as the square of its distance from the source of light; and upon the fact that the distances of two independent sources of light can be so adjusted that their illumination of the given surface is equal. Then by measuring these distances the relative illuminating powers can be calculated.

The fundamental principle of the Rumford or 'shadow' photometer can perhaps be best illustrated by means of simple familiar apparatus such as that in fig. 284.

It consists of an upright ground glass screen having fixed in front of it a small vertical rod. The standard light – in this case a candle – is placed at such a distance as to project a shadow of the rod upon the screen. The lamp, or other source, to be tested, is then brought into position so as to throw a second shadow close to that from the candle, and the exact position of the lamp so adjusted that the intensities of the shadows are as nearly alike as the observer can tell. The distances of the candle and the lamp from the ground-glass screen are then carefully measured and the comparative luminosities deduced from the

law of inverse squares For example, suppose the distance of the candle to be 12 inches, and that of the lamp 3½ feet when the shadows are equal, then the luminosity is $1^2 : 3\frac{1}{2}^2$, that is the light emitted by the lamp is 12¼ times as strong as that from the candle, and it may be called a 12¼ candle power lamp. The comparative sensitiveness of the observer can be roughly estimated by moving the lamp to and fro for some distance, when, unless he is a professional photometrist, he will probably find that it is a very easy matter for the personal error to exceed 10 per cent.

FIG. 284.

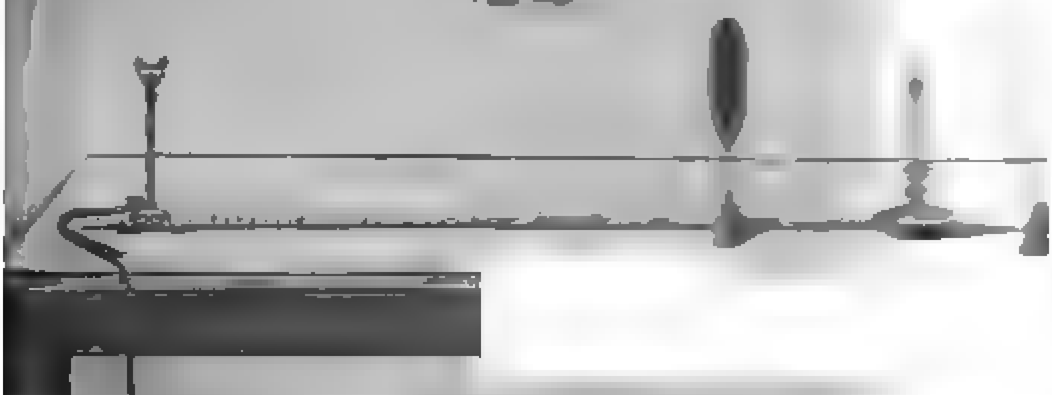
The principle underlying this instrument is simple, for it is evident that the shadow cast by the lamp is illuminated by the candle, while that cast by the candle is illuminated by the lamp, so that, if both shadows are reduced to the same degree of intensity, it can only be due to the effect of equal luminosities upon the surface of the screen derived from the two sources.

The Bunsen or, as it is often called, the grease spot photometer is, especially for the beginner, an instrument by which more accurate results can be obtained; and it is the one most frequently employed. The principle of the apparatus is shown in fig. 285. A small screen of somewhat opaque paper is stretched on a metallic ring, which is mounted on a stand, movable along a graduated scale In the earlier forms of this instrument, a semi-transparent grease spot was made in the centre of the disc by means of a little spermaceti dissolved in naphtha, but in the modern practical instrument, the whole of the paper, with the

...ption of a small central [illegible] ...cient screen is a matter of [illegible] ...ir thickness of spermaceti, which [illegible] ...y best results.

The standard candle is fixed [illegible] ...-jet, or lamp (the luminosity of which is [illegible] ...r end of the scale, which [illegible]

[illegible]



...e 100 or some multiple of [illegible] ...uld be placed [illegible] ...n the centre of the screen, [illegible] ...e scale until the spot [illegible] ...rface appears to be [illegible] ...ndle can be fixed and the [illegible] ...ale to the required place.

The bottom of the stand carrying the screen [illegible] ...lso be furnished with an index, and the [illegible] ...n the scale being noted, the relative distances of [illegible] ...ants from the screen can be easily ascertained. [illegible] ...es can then be calculated by squaring [illegible] ...rinciple of this instrument is [illegible] ...s held in front of the screen, the greased [illegible] ...ortion of the light falling upon it [illegible] ...ppears, when viewed from that side [illegible] ...o be darker than the ungreased portion [illegible] ...he rays falling upon it. [illegible] ...ehind the screen, the grease spot [illegible] ...paratively bright surface upon a dark ground, [illegible] ...hat the greased paper transmits a large portion of the

of the Bunsen photometer are, as we have indicated, generally employed. The form most frequently met with is the Letheby, which was designed for gas testing, and which therefore possesses many refinements unnecessary for electric light testing. The Bunsen disc is enclosed in a double conical tube or box to screen off extraneous rays of light, and small angular mirrors are placed opposite a pair of openings in the side of the tube, to facilitate observations of the two sides of the disc. The 'Universal' photometer, designed by the late Mr. Hartley, is simple, cheap, and efficient, and can be used for estimating the luminosity of arc or incandescent lamps, in a horizontal or in any other direction. It consists of a long narrow table, with two parallel grooves in the top; sliding in one of these are the Methven screen or other standard and the Bunsen disc, while in the other travels a scale, 21 inches in length, divided into tenths of an inch. For horizontal measurement, the lamp to be tested is fixed on an independent pillar at a known distance from the disc; if the lamp is suspended from the ceiling, an angle measurer is provided to facilitate the estimation of its actual distance.

It is the usual practice for an incandescent lamp to be carefully compared with some standard, such as the Methven screen. It is then in its turn, employed as a standard of comparison for other similar lamps, requiring little attention, and affording a ready means of rapidly testing a large number of lamps. It is, however, only employed as a standard for a time, otherwise there would be some risk of error owing to a variation in the luminosity of the lamp. The method of testing arc lamps is somewhat similar. An incandescent lamp, after being standardised, is in this case, also, frequently employed as a standard, the arc lamp being placed on a scale at right angles with the photometer bar, which carries a mirror adjusted to an angle of 45° with the luminous beam, so as, in obedience to the law declaring that the angle of reflection is equal to the angle of incidence, to project the rays upon the greased disc, the quasi standard being placed so as to illuminate the opposite side of the disc. The comparison is then made by adding the distance between the disc and the mirror to the distance between the mirror and the arc, and regarding this as the distance which has to be compared with that between the

sc and the standard A constant allowance has to be made for e absorption of the mirror, which for a certain angle varies with fferent samples of glass. It is obviously necessary that the arc ould be so screened that none of the rays fall direct upon the sc, and that the angle of the mirror should be kept fixed. ith a very powerful arc it would be possible to diminish the rcentage of the rays falling upon the disc, by placing the lamp a greater angle than that of 90° with the scale board or the is of the disc. A fresh constant would then have to be employed, accordance with the law that the intensity of illumination which received obliquely is proportional to the cosine of the angle hich the luminous rays make with the normal to the surface, lowance being also made for the increased loss due to absorption.

Where the space can be afforded, a photometer room should e provided, and fitted with opaque blinds, so that all extraneous ys can be excluded. The room, when candles or comparison ames are employed, should be free from draughts and vibrations.

CHAPTER XVII.

[illegible] EQUIPMENT, FITTINGS, ETC.

[illegible] details to be considered in co[illegible] [illegible] the means to be adopted f[illegible] [illegible] to the lamp. In [illegible] [illegible] whether the [illegible] [illegible] measures [illegible] the number of primary cells [illegible] [illegible] varied according to [illegible] [illegible] speed system of [illegible] [illegible] purpose, [illegible] strong, [illegible] [illegible] to [illegible] the [illegible] too great to permit the [illegible]

In [illegible] is always employed for [illegible] [illegible] The current to be carried is usually very strong [illegible] [illegible] energy due to the [illegible] [illegible] down to the lowe[illegible] [illegible] it would be nec[illegible] [illegible] the copper to [illegible] [illegible] such dimen[illegible] [illegible] would be too [illegible] [illegible] [illegible]

[illegible]

is only one-fourth of that of a wire half an inch in diameter, it does not cost anything like four times as much not even twice as much to lay the thicker wire as it does to lay the thinner, for the

Number of wires in strand	Standard gauge of each wire	Diameter (in inches): Of each single wire	Diameter (in inches): Of the strand	Equivalent to solid wire: Diameter (inches)	Equivalent to solid wire: Area (square inches)	Weight of Conductor per statute mile (lbs.)	Resistance [illegible] per [illegible]
1	22	·028	—	·028	·0006	12	72·42
1	21	·032	—	·032	·0008	16	[illegible]
1	20	·036	—	·036	·0010	21	[illegible]
1	19	·040	—	·040	·0012	26	[illegible]
1	18	·048	—	·048	·0018	[illegible]	[illegible]
1	17	·056	—	·056	·0024	50	[illegible]
1	16	·064	—	·064	·0032	65	[illegible]
1	15	·072	—	·072	·0040	83	[illegible]
1	14	·080	—	·080	·0050	[illegible]	8·684
1	13	·092	—	·092	·0066	135	6·718
1	12	·104	—	·104	·0085	173	5·257
1	11	·116	—	·116	·0105	215	4·225
1	10	·128	—	·128	·0128	262	3·470
1	9	·144	—	·144	·0162	332	2·742
1	8	·160	—	·160	·0201	409	2·221
3	25	·020	·042	·034	·0009	19	[illegible]
3	23	·024	·051	·042	·0014	28	[illegible]
3	22	·028	·059	·049	·0019	38	[illegible]
7	25	·020	·060	·053	·0022	45	[illegible]
7	23	·024	·072	·064	·0032	65	[illegible]
7	22	·028	·084	·075	·0044	89	10·20
7	21½	·030	·090	·080	·0050	102	[illegible]
7	20½	·033	·099	·088	·0061	124	[illegible]
7	20	·036	·108	·096	·0072	147	[illegible]
7	19	·040	·120	·107	·0089	182	[illegible]
7	18	·048	·144	·128	·0128	262	3·473
7	17	·056	·168	·149	·0174	350	[illegible]
7	16	·064	·192	·171	·0229	465	[illegible]
7	15	·072	·216	·192	·0289	589	1·543
7	14	·080	·240	·213	·0356	727	1·253
19	20	·036	·180	·159	·0198	402	2·261
19	19	·040	·200	·176	·0243	496	1·831
19	18	·048	·240	·211	·0349	715	1·271
19	17	·056	·280	·247	·0479	973	[illegible]
19	16	·064	·320	·282	·0624	1,270	[illegible]
19	15	·072	·360	·317	·0789	1,608	[illegible]
19	14	·080	·400	·352	·0973	1,985	·4579
19	13	·092	·460	·404	·1282	2,625	[illegible]
19	12	·104	·520	·458	·1647	3,354	·2709
37	16	·064	·448	·394	·1219	2,482	[illegible]
37	15	·072	·504	·443	·1541	3,142	[illegible]
37	14	·080	·560	·493	·1859	3,879	[illegible]
37	13	·092	·644	·566	·2510	5,130	[illegible]
37	12	·104	·728	·640	·3217	6,555	[illegible]
61	13	·092	·828	·728	·4162	8,177	[illegible]
61	12	·104	·936	·823	·5319	10,832	·0809

labour of removing and replacing the paving, earth, &c., would be almost the same in both cases. Again the insulation of the wire is an important and expensive item, which does not increase so rapidly as the resistance of a wire is reduced by an increase in its size; so that it does not by any means follow that a given reduction in resistance entails a proportionate increase in expense. It may be noticed incidentally, that when the diameter of a round conductor is doubled, although its sectional area and therefore its conductivity is increased four-fold, its surface is only doubled. Therefore if a current of four times the strength is passed through it, the heat developed will be four times as great (since power wasted = C^2R), while the surface at which radiation takes place has only been doubled. The temperature of the thicker wire will rise higher than that of the thinner one, when they carry currents in proportion to their conductivities.

One advantage attending the use of bare conductors is the greater facility afforded by them for the radiation of heat as compared with covered conductors.

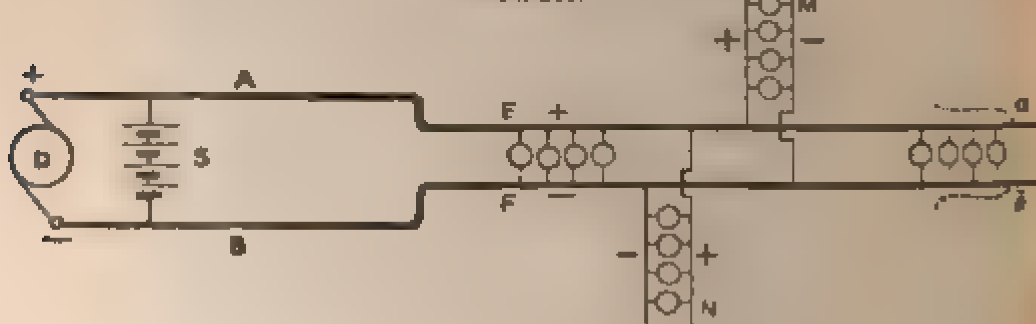
So many considerations, mostly special for every particular case, enter into the question of the best size and shape of the conductor consistent with strict economy, that we cannot discuss the matter fully here. But with regard to the reduction of resistance by the employment of high conductivity copper, it should be noticed that as the presence of a minute quantity of foreign matter causes such a great increase in the resistance of this metal, it is *always* economical to use the purest copper obtainable commercially.

In systems of distribution of electrical power by means of a constant current, the question is comparatively simple, as the current employed is not a heavy one, and has the same value at all times and in all parts of the circuit. The chief difficulty likely to arise is in providing for future extensions of the system when the potential difference which can be applied at the ends of the circuit is limited. The more interesting and more difficult problem consists in the supply of current to lamps, or other apparatus, at a constant potential; for then the main conductors have to carry a very heavy and variable current. The matter becomes more difficult if the lamps are distributed over a wide area, or are situated at a distance from the generating station. As has been

pointed out in Chap. XIII., the power wasted may in such cases be reduced to a minimum, by transmitting it in the form of a small current at high pressure, and reducing the pressure at the required point, to a suitable value. But such a system has its disadvantages. Although the cost of the copper is vastly reduced, the high potential difference employed demands very efficient and expensive insulation, the engines and dynamos must always be kept running, and when very little power is being demanded the efficiency of the transformers and of the whole system falls to a low value. For even when the secondary circuit of a parallel transformer is disconnected, some current passes through the primary, and when only one or two lamps are joined up, the power appearing in the secondary may be but a comparatively small fraction of that absorbed by the primary. When the number of transformers is large, the total power wasted becomes considerable during the times when little or no light is required.

In the other method of distributing direct from the dynamo to a number of lamps all joined up in parallel, the chief problems to be faced are the heavy loss occurring in the mains and the difficulty of regulating the supply to each lamp.

FIG. 286.



Such an arrangement is indicated by the diagram in fig. 286, where D represents a dynamo capable of maintaining a constant potential difference at its terminals; A and B, the main leads from the machine to the nearest lamp; and E, F the continuation of those leads, between which the lamps are placed. Suppose there to be 100 lamps so joined in parallel, each requiring a current of half an ampere, and a potential difference at its extremities of 110 volts. The total current supplied by the dynamo with all the lamps in use would be 50 amperes, and this current would

have to be carried by the main leads A and B. Supposing the resistance of A and B to be one-tenth of an ohm, the power wasted in overcoming this resistance would be 250 watts, and the consequent fall of potential 5 volts. Therefore the machine must develop at least 115 volts at its terminals in order to maintain 110 volts at the *nearest* lamp.

Now a further fall of potential would take place along the mains, E, F; suppose this to amount to 10 volts, then the pressure at the most distant lamp would only be 100 volts, while if this were raised to 110 by an increase at the dynamo, the nearest lamp would then be working at 120 volts. Even ignoring the waste of power, such a difference could not be permitted if similar lamps were used throughout the system, as some would be giving far above and others far below their normal candle-power.

It would, however, be practicable, but very inconvenient, to employ different types of lamp, placing those made to run at 110 volts at the end near the dynamo, and others constructed for 100 volts at the further end of the line, and so on. But even then, if the dynamo were perfectly regulating, the potential at the far end of the mains would rise considerably, when any number of the nearer or intermediate lamps were cut out of circuit.

Referring again to the figure, it will be observed that the mains at any one point only carry a current equal to that required by the lamps beyond that point. Thus, while the portions, A, B, the whole current, those portions between the last lamp the last but one only carry half an ampere. The size of mains might, therefore, be reduced by one hundredth as lamp is passed, and the same density of current in the be retained. This is equivalent to bunching 100 wires form the main, and taking out one of them at 100 wires were separately insulated, that is to lead and return wire were used between the and each lamp, the pressure at the ends of constant; and since the resistance in circuit is also constant, the pressure at unaltered by any variation in the number forms a means of maintaining a perfect course the actual pressure at the lamp

resistance of its particular leads. Great as are the advantages of such a method, the expense would forbid its being employed in an installation extending over a large area. It will be seen, however, that with ordinary mains, if the resistance is sufficiently low to make the fall of potential very small, then the variation which would take place in the potential difference at the extreme end of the circuit becomes negligibly small. An extreme variation of 4 volts might be allowed, and then, by maintaining the normal pressure of 110 volts near the middle of the system, the nearest lamp would have but 112 volts and the furthest 108.

It is necessary to be able to observe in the engine-room the pressure existing at the far and near ends of the mains at any moment, so as to be able to keep one point as much below as the other is above the normal pressure; and this can be done by leading 'pilot-wires' from the mains at those points to a voltmeter placed at the generating station.

For instance, in fig. 286, a thin wire might be led from the point *a* and another from *b*, each to one terminal of the voltmeter, which would afford an indication of every variation at the extreme end of the mains. A second pair of pilot wires might be led from the nearest lamp; or by leading one pair only, connected to the mains at the centre of the system, and keeping the potential there at 110 volts, a good average regulation might be maintained.

At an installation at Kensington Court, over two thousand 100-volt lamps are run in parallel, batteries of secondary cells being used in conjunction with the dynamos, for regulating, and assisting the machines to meet any large demand. Several circuits branch out from the engine-house, some of the lamps being 900 yards distant. At the extreme ends of all the mains, a pressure of 100 volts is maintained, while that at the nearest lamp does not exceed 102 volts. A pair of thin wires is led, as mentioned above, from the end of the mains, to a voltmeter in the engine house, and when this instrument indicates a fall of potential (caused by the switching in of more lamps) the attendant immediately switches one or two secondary cells on to that pair of mains, in series with the existing cells, thus raising the pressure to the required value; the cells being of course cut out when the voltmeter indicates a rise of potential. The mains employed in this case consist partly of

ordinary insulated cable, and partly of bare copper conductors stretched over porcelain insulators, in concreted channels.

Although on a simple parallel system of distribution, the arrangement is such that the whole of the lamps are connected in parallel between the two mains, it is evidently impracticable to join them directly across (as indicated in the case of the nearest and furthest lamps in fig. 286), when the mains are carried under the roadway. It is necessary to lead a wire from each main to every group of lamps, say to every house supplied, in the manner indicated at M, N. The higher potential mains are throughout marked +, and the lower potential, or return wires −. These subsidiary mains should be proportioned in size according to the number of lamps to be supplied by them.

It is not possible, however, to sufficiently reduce the resistance of a single pair of mains leading direct from the dynamo to maintain even approximately a constant pressure at all the lamps if they are distributed over a large area; a method of facilitating regulation in such a case, by the employment of subsidiary mains which feed the mains proper at certain points, but are not themselves tapped by lamp circuits, will be described later on.

The method of employing a battery of secondary cells so as to assist in the regulation, or in the maintenance of a constant potential, is indicated in fig. 286, where S represents such a battery. The cells are joined in parallel with the dynamo, and are charged by it without any alteration in the connections being necessitated.

The interactions between the two generators—the dynamo and the battery—may be embraced under three heads. (*a*) When the E.M.F. of the battery is less than the potential difference at the dynamo terminals, the machine is supplying current to the lamps and at the same time charging the cells, the strength of the current passing through the cells depending upon the excess of the potential difference maintained by the machine over the E.M.F. of the cells. (*b*) When the E.M.F. of the cells becomes equal to the potential difference at the machine terminals both generators are equally active in feeding the lamp circuit. (*c*) When the E.M.F. of the cells rises above the normal—that is, above that potential difference which is required to be maintained at the terminals of the generators in order to maintain the right pressure

at the lamps—then the battery not only feeds the lamp-circuit but raises the pressure at the machine terminals. This may happen, but the machine being shunt wound, the effect is to increase the current through the field coils, giving a stronger field, which again tends to increase the E.M.F. developed. When the potential difference thus rises, it becomes necessary to cut out one or two cells to prevent the pressure rising sufficiently high to injure the lamps. A suitable switch is employed for this purpose, and the regulation effected by an attendant in accordance with the indications of the voltmeter.

It will be remembered that if the engine should break down, the cells would drive the shunt machine as a motor in the same direction; but an automatic cut out should be provided to cut off the dynamo when the back-current from the cells exceeds a certain limit. A piece of apparatus capable of performing these operations was described in Chap. XIV.; it disconnects the machine when from any cause its potential difference falls below the E.M.F. of the cells. Under such circumstances the cells would be called upon, and should be able, to run even the whole of the lamps for a short period, or a portion of them for a considerable time.

It also becomes possible to economise power and the expense of attendance, by only running the machine during the hours when the demand is a maximum, allowing the cells to supply current to the few lamps required at other times.

It may occur to the student that a considerable saving in the mains would be effected by joining groups of lamps in series between the mains, all the groups being thus placed in parallel. This is so; for if the lamps were placed in sets of four in series, the potential difference between the mains would be four times that at the ends of one lamp, say 400 volts instead of 100. By this means the maximum current in the mains would be reduced to one-fourth, and the weight of copper correspondingly reduced, to give the same rate of loss of power.

But some serious difficulties arise in connection with such a system; for instance, if the filament of one lamp in a set breaks, the other three lamps in that set are immediately extinguished; and if, to remedy this, the faulty lamp is merely short circuited, the remaining three get too much current, and may also be

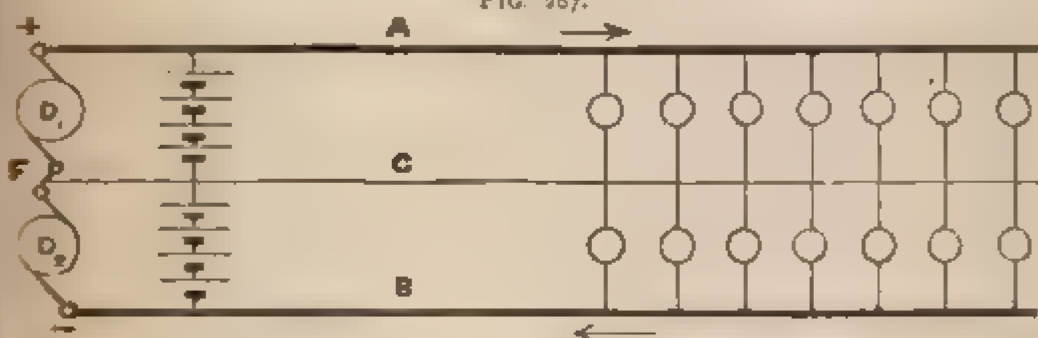
damaged. Of course a device may be adopted to automatically switch in a second lamp, or to replace the broken one by a resistance equal to it; but the latter arrangement is undesirable on account of the waste of power; and in either case the extra fittings cause additional trouble and expense.

The same objection arises in the ordinary case of switching out one of a batch of lamps.

But even if the lamps are joined in sets of only two in series, a considerable saving is effected; and a method by which this can be done without introducing any of the difficulties referred to is indicated by the diagram in fig. 287. It is known as the 'three-wire system.'

Two equal dynamos, D_1, D_2, are joined in series, and connected to the mains, A, B, in the ordinary manner. That is to say, the positive terminal of D_1 is joined to the positive main, A, and the negative terminal of D_2 to the main, B, while the negative ter-

FIG. 287.



minal of D_1 is coupled to the positive of D_2. Suppose each machine to be capable of maintaining a potential difference of 110 volts; then when they are so joined in series they maintain the mains A and B at a difference of 220 volts The lamps being joined, two in series, across the mains as indicated, the potential difference at the extremities of one of them is 110 volts. A third wire, C, much smaller than the mains, connects the junctions of the pairs of lamps, and is also joined to the junction of the dynamos.

Now when the number of lamps between A and C is the same as the number between B and C, the potential is the same at every point along the wire, C. Hence there is no tendency for any current to flow along the centre wire; it might, in fact, be cut at any point, or removed altogether, without in any way affecting the

working of the system. But when the lamps on either [illegible] are made unequal in number, this state of balance [illegible] exists. Suppose a lamp between A and C to be sw[illegible] circuit; then the resistance between A and C is greater than between [illegible] fore the fall of potential becomes greater, than between [illegible]. But the mains A and B are kept at approximately the same potential difference, and if the difference between A and C [illegible] increased, it can only be by the lowering of the potential of [illegible]. The effect of cutting out a lamp between A and C, then, is to lower the potential of C near the point where the lamp is [illegible]nected. But the potential at the point F remains unaltered; [illegible]sequently this difference of potential establishes a current [illegible] the wire C, from the junction of the [illegible] to the lamps [illegible] strength is equal to that which flows through one lamp [illegible] may, in fact, be considered as the current which passes [illegible] the additional lamp between B and C. If a lamp between [illegible] is now switched out, balance is again restored, and no [illegible] passes along C. When the number between A and C is [illegible] greater, the difference between those leads is lessened, the [illegible] potential of C near the lamps is raised. This determines [illegible] of a current from the lamps to the junction of the mains [illegible] the centre wire. If the whole of one set of lamps [illegible] then the centre wire would have to carry the [illegible] all the lamps in the remaining set, in wh[illegible] to be as large as the other mains. [illegible] mains are made equal, but it is usually [illegible] lamps so that this [illegible] the case [illegible] current wh[illegible] favourable conditions [illegible] the [illegible] cases, due to the [illegible] [illegible] the [illegible]

It has been [illegible] means of which [illegible] [illegible] may [illegible] secondary [illegible]

es, as indicated in the diagram; two complete sets of cells ...ded, their positive and negative terminals being connected ...mains and to the centre wire in the same manner as are the ... terminals.

...eans of reducing the difficulty of maintaining a uniform ...al difference along lengthy mains, is afforded by the use of ...ndent conductors connecting various points in the circuit with the generating station, and these subsidiary leads are ... 'feeders.' In some cases the mains themselves are not ...ted direct with the generator, the whole of the current ...supplied to them at suitable points by way of the feeders. ...the potential difference at or near the particular point to ...a pair of feeders is connected, varies (as it does, with a ... in the number of lamps in use), this difference is com...d for by correspondingly varying the pressure applied ...feeders, or by some other means varying the current pass...ough them. When, for instance, the number of lamps in ... increased, the pressure between the mains falls, and more ...s required to be supplied by the feeders, and *vice versâ*.

...comes necessary, therefore, to provide some means for ...indicating, at the generating station, the variations of the ...difference at the points where the feeders join the mains. ...adily supplied by the employment of pilot wires, after ... already described, these wires being simply connected ...eter. When the instrument shows a fall of potential, ...al pressure along the pair of feeders is augmented ...tant point is raised to the required standard. On the ...should the potential difference in the mains rise, then ...eeders must be reduced. But economical adjustment ...s somewhat difficult of attainment. It would, for ...rdly pra... to use a separate dynamo for each ...and ... vary its output to suit the demand. ... more dynamos connected to a ... the whole of the feeders ...tween these bars must be ...d the regulation can then ...ater electro-motive force

The insertion of resistance coils, however, while [illegible] and convenient, is wasteful. A more economical [illegible] have a few secondary cells in each feeder, so [illegible] they oppose the feeding current. The effect is simp[illegible] a counter E.M.F. to the dynamo (since the cells have [illegible] resistance), but the potential difference is varied by the steps of two volts at a time. In making any change [illegible] must be [illegible] treated.

With the three wire system it is obviously nec[illegible] three feeding wires to each point and to connect pilot [illegible] from to two separate voltmeters.

The advantage of using several comparatively sma[illegible] joined in parallel to supply the omnibus bars is that a d[illegible] be switched out and stopped when the demand for cur[illegible]

When the feeders vary considerably in length, it may [illegible] able to divide them into two or even more groups acc[illegible] their resistances, and supply the longer ones from a pa[illegible] maintained at a proportionately higher pressure than th[illegible] bars supplying the shorter feeders.

Turning now to the methods of supporting, protect[illegible] insulating the conductors, we immediately observe th[illegible] naturally divide themselves into two classes, viz., overh[illegible] underground.

The overhead system has th[illegible] of cheapness [illegible] struction, and it affords great [illegible] and the subsequent extens[illegible] ployed where the local cond[illegible] employed is not so heavy as t[illegible] and where the potential dif[illegible] system has [illegible] the d[illegible] to consist[illegible] extent [illegible] of proper[illegible] for arc or [illegible] to the emplo[illegible] cases const[illegible] wire would be [illegible] really determin[illegible]

For example, a wire of No. 12 B.W.G. would carry the current with safety, but a No. 8 or No. 10 is practically used on account of its greater strength. When the conductor is stranded, 7 No. 16's are employed, although 7 No. 20's would, from an electrical point of view, suffice. We ought perhaps to mention that all overhead bare conductors must be of hard-drawn copper in order to obtain the requisite mechanical strength. Ordinary pure copper is comparatively soft, and in a span of any considerable length cannot sustain its own weight; while in a gale, the wind pressure enormously increases the strain upon the wire.

Bare conductors are supported on insulators which are in turn supported by poles either of iron or wood according to local circumstances. One advantage pertaining to wood is that in the event of an insulator breaking, the conductor is still partially insulated from the earth, which would not be the case were an iron pole employed. Iron poles are obligatory for over-house work, or where appearance has to be taken into account. The best pole is that which consists of the complete trunk of a straight larch or other similar tree, which, after having been well seasoned, is thoroughly impregnated with good creosote. The natural life of the pole is enormously lengthened by this treatment. A convenient compromise is often effected by fixing a wooden top into an iron socket.

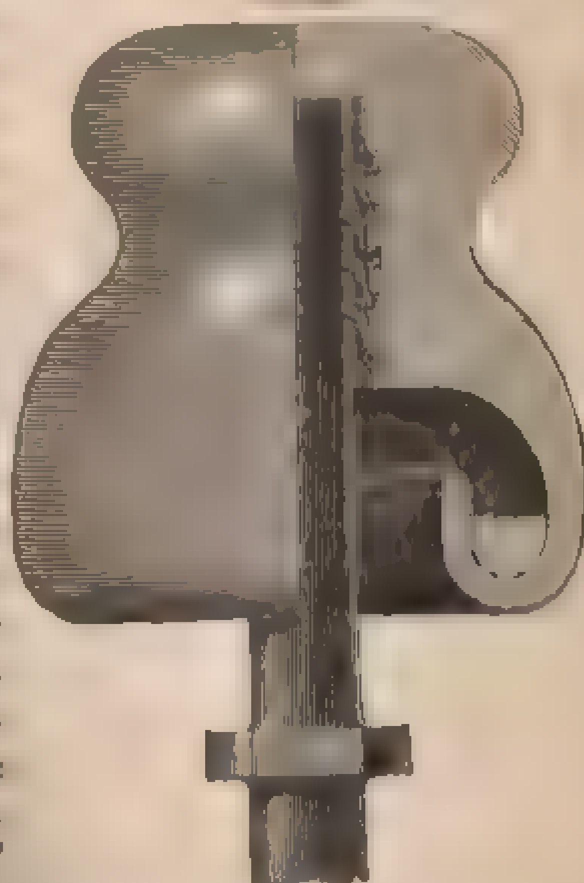
Insulators can be made from a variety of substances, but for climatic and other cogent reasons, white glazed porcelain is most frequently employed.

The chief requirements are hardness, smoothness, and imperviousness to moisture. Lacking either of these, the insulator is practically useless. It should be hard in order to resist abrasion by the wire; it should be smooth to prevent the accumulation of dust and dirt, to facilitate cleansing by rain, and to avoid the unnecessary wearing away of the conductor; and it should be impervious to moisture, in order that the rain should fall off instead of entering the pores of the substance and reduce, more or less permanently, its insulating properties.

Brown earthenware, made from clay, is, taking all things into consideration, also a good material. It is very hard, very durable, has a high resistance, and the glaze which it can take,

[illegible] the event of fracture, the insulator itself can be replaced with[illegible] the conducting [illegible] the [illegible] The method [illegible]ing the wire [illegible] insulator is [illegible]ated in fig. [illegible] The conductor is laid in [illegible] groove, and a [illegible] of thin binding wire, three or four feet long, is twisted several times round the conductor on one side, A, of the insulator; it is then wound round [illegible] insulator and is next [illegible]ed several times round [illegible] conductor on the other [illegible], after which it is wound again, round the insu[illegible] once more, and again [illegible] the conductor on the [illegible]. Sometimes the binding [illegible] are soldered.

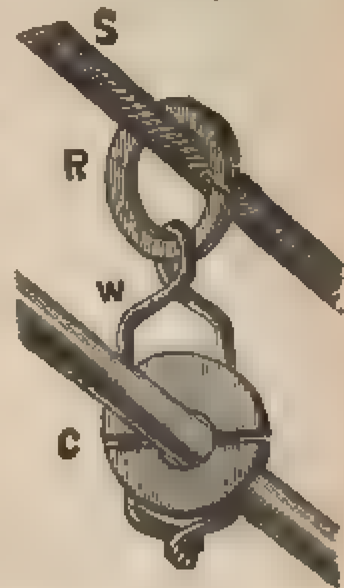
[illegible]hen high potential differences are employed, no [illegible] or expense should be [illegible] to ensure the most [illegible] insulation possible. [illegible] of insulator very [illegible] this purpose [illegible] avoid dis[illegible] leakage [illegible] fig. [illegible] [illegible] a [illegible] the path of leakage, the lip of the [illegible] the inner side to form a circular



insulators of ...
bolt passing ...
bolted to the ...
main wire ...
by a small ...
insulator ...
freedom of ...
makes an ...
When an ...
... work would ...

, and that at the very point where complete insulation is viz., at the insulator itself. There is also the further diffi- at an ordinary covered cable has not sufficient tensile to enable it to support its own weight in a span of any able length. In such cases, a steel wire or rope S (fig. 292), rted by shackle insulators, and a number of split steel rings, R. g in each ring is a galvanized iron p W, which supports a vulcanite and through which the cable is

Fig. 292.



etimes the conductor is suspended between a pair of steel ropes by of V-shaped pieces of iron wire, ce being attached to three small white porcelain threaded one on to uctor and the others on the ropes. of the most important details in on with the running of electrical ors is that of jointing. The chief features which should to a well-made joint are, that the electrical continuity be fully maintained, that its mechanical strength should st equal to that of the conductor itself, that no free ends be left on the finished joint, that it should be durable ctrically and mechanically, that it should be as compact le, and that with a covered wire the insulating coating e made continuous and as uniform as possible

solid conductors up to a quarter of an inch or so in ; there is no better joint than that known as the ia' (fig. 293), which illustrates a joint of this kind made

Fig. 293.

two lengths of No. 8 B.W.G., bound with No. 16. The the two conductors are carefully scraped and laid side for a distance of about two inches, about an inch or so tremity of each of them, having been previously bent up at

right angles to the axis of the wire. They are then wound over tightly, with several turns of thin binding wire. The binding is commenced on one of the wires only, round which four or five turns are wound; it is then continued as close as possible over the two wires, until the turned up portion of the second wire is reached, a few turns continued round the single wire completing the winding. The joint is finished by carefully and completely soldering it into one mass, and cutting off the then protruding ends of the wires, stray pieces of solder, &c. A joint made in this way approaches as nearly as possible to perfection, for its resistance is less than that of the other portions of the conductor, and its mechanical strength is much greater.

The method of jointing a covered stranded conductor is simple. Supposing it to be a 7-wire strand, the insulating covering is removed from each end for a distance of a few inches, care being taken to avoid nicking the copper. All the separate wires are then opened out and the centre wire on each of the ends to be joined, is cut off short. The two sets of wires are next brought end to end, and laced together, just as would happen when two hands are placed palm to palm, and the fingers of one hand placed between those of the other. This being done, the protruding ends of each conductor are wrapped closely round the other, the two wrappings being in opposite directions. The joint is then trimmed round with the pliers, and the whole well soldered together. The soldering is a more important matter than would at first sight appear, since the solder is relied upon to maintain the electrical continuity. Every care should therefore be taken that the copper surfaces are scraped clean before making the joint, that they are not handled more than is absolutely necessary, and that steps should be taken, as far as possible, to prevent oxidation. A very good plan is to use tinned wire, and to employ only resin as a flux. The conductor-joint having been completed, the insulating covering is then made good. If the material is gutta-percha, the conductor is wrapped with several layers of gutta-percha tissue which is softened by warming with a spirit lamp, and kneaded by the fingers to expel air bubbles. A few layers of gutta-percha strip are afterwards similarly applied, warmed and surfaced up with a warm metal tool, prepared tape being wound

to complete the joint. When the insulating material is india-ber, strips of pure rubber are employed instead of gutta-cha.

When the conductors are to be laid underground, the chief ficulty to be contended with is the provision of efficient and able insulation. The simplest method is to support the bare nductor by suitable insulators, after the manner described in apter XII. The distance between the insulators depends her upon the rigidity of the conductor, or upon the tension ich it can withstand. Since every insulator is a point of leak-e it is obviously necessary that their number should be reduced far as possible.

In some electric lighting installations the bare conductors are pported by ordinary porcelain insulators fixed in a brickwork nduit with a concrete lining. In others, such as that in the ll Mall district (London), in which the three-wire system is em-oyed, the mains are carried in underground channels almost long in section, and made of cast-iron. At the junction of jacent lengths a groove is formed in the sides of the channel, in ich, at right angles to the length of the channel, is fitted a stout rcelain slab. The under edge of the slab is arched to allow the e flow of water along the bottom of the channel. The slab s also three deep vertical slots across the top, the centre one ing somewhat narrower than the other two. Each conductor nsists of a number of bare copper strips placed edgeways in the ts, and drawn tight enough to prevent contact laterally, while e depth of the strip is sufficient to prevent sagging. The ntre conductor is formed of fewer strips than the outer mains; ile the conductivity of all of them can readily be reduced yond the points where branch circuits tap the mains, by reduc-g the number of strips. Long experience with underground ambers and channels, such as are employed for many other rposes, has shown that it is impossible to prevent the accumula-n of water within them; hence the necessity for amply provid-g for the ready escape of water, that is to say, the conduit must well drained. Electric light engineers have not yet had a suffi-ntly lengthy experience to enable them to appreciate fully the l difficulties which await them, such as those due to the corro-

sion of the iron and the falling of scale from the roof and sides of the channel; and to the incrustations and fungoid growths which manifest themselves in damp underground chambers. It would appear to be essential that good drainage should be supplemented by ample ventilation. Even were a conduit to be made water-tight there would still be sufficient moisture caused by condensation to oxidise the iron and make the surfaces of the insulators damp; although the passage of a heavy leakage current tends to dry the surface over which it passes.

It will, however, be evident that were the pipe containing the conductors filled with some good liquid insulating material, this accumulation of moisture with the attending disadvantages would be avoided. Paraffin oil is a liquid which has remarkably high insulating properties, and is, therefore, suitable for this purpose, but with a conduit constructed in the ordinary way, the quantity of oil required would be enormous. On account, however, of its high specific resistance, a thin film suffices to prevent leakage from one conductor to another, even though the potential difference between them be very great. The Brooks system is based upon this principle. So far the only application of it in this country has been to telegraphy, where, however, it has proved to be both reliable and economical under almost the worst possible conditions. A cable was made of forty cotton-covered copper wires of about No. 18 B.W.G. These were bound round with ordinary braid and drawn into a wrought iron pipe of about $1\frac{1}{4}$ inch internal diameter, the length of the cable being about $1\frac{1}{2}$ mile. The ends of the pipe by which the cable enters and leaves were sealed for a distance of two or three yards with paraffin wax, and paraffin oil was then supplied from a reservoir placed at one end at such a height as to be above the level of the other end. The joints in the pipe were made as secure as possible, but for some time the line was subject to a series of faults, caused by the leakage of the oil. The average loss may be put down at about thirty gallons a month, although from February to September 1889 only thirty six gallons had to be added. It is essential that the pipe should be not only water-tight, but also paraffin tight. The paraffin has, in fact, been known to exude through the iron itself, and stand in small beads

on the outer surface; hence the necessity for using the best wrought-iron pipes. The chief objection to the system, the insulation resistance of which is almost infinite, is that it affords few or no facilities for branching or T-ing

The insulation resistance being practically infinite, the system merits the serious attention of electric light and power-transmission engineers; but in cases where the mains are tapped at frequent intervals, the difficulty of making the branch connections will probably prove a serious drawback. In telegraph work, when two or more of the conductors get into contact, through the leakage of the oil, the fault is removed by refilling the reservoir, and so forcing more oil into the pipe; but a serious accident might arise from such a fault were the conductors to be employed for the transmission of heavy currents or currents of high potential difference. Some substance other than paraffin wax would also be required for sealing purposes, for were the conductors to become heated through a short-circuit, the wax would be melted and the oil allowed to escape.

Another method of insulating underground conductors, and the one generally adopted, is to cover the copper with some durable substance of high specific resistance, such as india-rubber or gutta-percha.

In all such cases it is essential not only to efficiently insulate the conductor, but also to protect the insulating covering from deterioration by exposure, and to protect the whole cable from mechanical injury. When these points are very carefully attended to, an installation with insulated underground cables for the mains is very reliable, and gives little or no trouble in maintenance But carelessness in manufacture or laying, or the use of inferior materials, gives rise to troublesome and most expensive repairs.

At present there is a tendency towards false economy in this matter. A thin covering of the insulating material is placed over the conductor, and when new and absolutely perfect the insulation may test higher than is actually essential in practice. But the slightest indentation or abrasion of the covering, such as may easily happen, and does happen, in handling during the process of laying, even if it does not quite expose the copper, leaves such

a weak spot that the development of a 'fault' there becomes only a question of time. The insulating covering, of whatever material, should be of reasonable thickness, not so much for the purpose of obtaining an extremely high initial insulation resistance, as to ensure its maintenance at a fairly good value. Gutta-percha must be used with caution. If not exposed to light and air it is practically imperishable, and it may therefore be used with advantage under conditions which are at all similar to those obtaining in the case of a submarine telegraph cable; but it quickly cracks and perishes if employed in a dry, airy situation. In such cases india-rubber would be preferable; but for underground work pure and simple there is very little to choose between these two substances. With rubber, the copper requires to be tinned in order to protect it against the sulphur which rubber insulation usually contains. Gutta-percha, however, softens at a lower temperature than does india rubber, and hence is more likely to allow the conductor to become decentralised when heated by the current.

These materials are the best available for insulating purposes, but they are expensive, and a large number of substitutes have been introduced. Some of them are fibrous in their constitution, and are impregnated with an insulating oil. Their specific resistances are lower than those of percha or rubber, but this is not a serious drawback provided the coating is sufficiently thick. They are not as a rule impervious to moisture, and require therefore a waterproof covering.

In some instances the temperature at which the compound softens is very high, whence the tendency to decentralisation is reduced.

Bitumen is a good insulating material, but it softens at a low temperature, and even at normal temperatures it is so plastic that the weight of the conductor itself would cause it to sink through the coating. The processes employed by the Callender Bitumen Co. overcome these objections. The material is vulcanised or treated with sulphur, with the result that, while retaining its high insulating properties, it becomes rigid and holds the wire permanently in position, even though the temperature of the conductor be considerably raised. The conductor is usually of stranded copper wire, tinned to protect it from the sulphur. It is

first coated with a sheath of the vulcanised bitumen, applied under heavy pressure in one solid layer to the required thickness This sheathing is then covered with cotton tape treated with bitumen, the number of layers ranging from one to five ; the cable is passed through a bath of hot compound after each serving of tape. The next process, for underground cables, is to apply a coating of jute yarn, and after another passage through the bath to cover it with hemp braid Most of the cables are subjected to this treatment, the higher degrees of insulation being obtained by increasing the thickness of the dielectric that is, of the vulcanised bitumen. For the smaller cables, such as are employed for indoor work, a layer of parchment tape is interposed between the conductor and the bitumen.

For important underground work the company has three distinct systems, the cables in all such cases being made as already described with the higher degree of insulation In the first of these systems, a rectangular cast-iron trough is laid in a trench. The troughing is made in six-foot lengths, the thickness of the metal ranging from three to five-sixteenths of an inch ; the internal dimensions vary according to the number and size of the cables, but in all cases the cable is kept at some considerable distance from the iron. One end of each length of the troughing fits into a socket made at the adjacent end of its neighbour. The two lengths are then bolted together and the joint sealed with bitumen The cables are supported by a number of wooden bridges, generally placed at intervals of two feet. Each bridge before being placed in position is treated with bitumen, and has two or more vertical slots, according to the number of cables, each slot being rounded at the bottom, and just wide enough to fit the cable A small quantity of natural or unvulcanised bitumen is run along the trough, and the bridges are imbedded in it before it solidifies. The cables are then laid in position in their respective slots, the dimensions of the wood being sufficient to keep them well clear of each other and of the iron. The trough is next filled up with pure bitumen and covered in with a one-inch layer of concrete, or an iron lid. It may be urged as an objection to this system that, the cables having been once laid, cannot in the event of a fault occurring be withdrawn ; but, on the other hand, the system permits

of such good work being put in that the chances of a breakdown can be made very remote.

The second of these systems is designed to allow the cables, which are similar to those used in the previous case, to be withdrawn separately. The channelling consists of blocks of bituminous concrete made in six-foot lengths and jointed by a saddle-piece of the same material. The blocks are provided with long uniform circular holes or 'ways,' varying in size and number according to the requirements, but only one cable is placed in each way. In most cases there are either two, three, or four ways, the diameters most frequently employed being $1\frac{1}{2}$, 2, or $2\frac{1}{2}$ inches.

Draw-boxes are provided at convenient intervals, and the blocks having been fixed together in the trench, the cables are drawn in. This system has also the advantage that, should the cable covering fail or give way, serious damage is prevented from the fact that the supporting material, *i.e.* the bituminous concrete, is a good insulator.

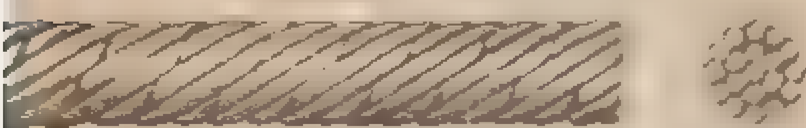
The 'saddle-pieces' embrace the sides and bottom of the blocks, and are provided with two grooves (one on either side of the joint), which are filled with bitumen.

In the third system the insulating material is fibrous in its constitution and is sheathed in lead. Over the conductor is wound a layer of parchment tape. Next to this is applied a rather thick layer of fine yarn, which has been dried at a very high temperature and then impregnated with boiling bitumen under pressure. The characteristic feature of this cable consists, in fact, in the processes adopted for the complete exclusion of moisture and air. Immediately after the impregnation is completed, and while the bitumen is still hot, the lead sheathing is put on direct with the aid of hydraulic pressure. The subsequent treatment varies with circumstances, but it is usually necessary to protect the lead from mechanical injury and the chemical effects of certain soils. For these purposes, the lead is passed through an asphalte bath and is then served with steel wire or ribbon, which is also covered with bitumenised tape or braid.

We have already described the method of making the splayed or long joint for stranded conductors, but in all Callender cables another form, known as the 'marriage' joint, is employed; a portion of the joint is illustrated in fig. 294. More skill and time are

make this joint than are involved in the ordinary [illegible] has the advantage that the conductor [illegible] throughout. It is also very strong and electrically [illegible] is wound separately round the others and is cut so that it abuts against the end of a strand from the [illegible] the joint. The end-to-end abutments [illegible] as [illegible]ls, as can be gathered from the [illegible], and the [illegible] soldered. The covering is made good by [illegible] of

Fig. [illegible]



[illegible]tical with those already on the [illegible]. In the case [illegible]eathing, an ordinary wiped joint [illegible], the uncertainty of always [illegible] [illegible]hod is not adopted. The [illegible] [illegible]nds of a cast iron joint box, which after the ordinary [illegible]ting has been [illegible] is filled up [illegible]. A similar [illegible]d with three [illegible] at a T-joint. [illegible]pe of electric [illegible] is manufac- [illegible]srs. Felten & [illegible] one form of [illegible]ed for one of [illegible] a three wire [illegible] incandescent [illegible]strated in fig. [illegible]anded core [illegible] copper [illegible] a layer of [illegible] the thickness of which [illegible] the [illegible] [illegible]ated by the [illegible] [illegible] layer of jute [illegible]

Fig. [illegible]

compound; and mechanical protection is afforded by a double sheathing of iron ribbon (shown white), the external covering being another serving of the impervious compound. This cable was constructed to be laid bare in a trench, and it contains the pilot wires which are necessary on an extensive parallel system. These two wires can be seen on the left of the conductor; they are of thin copper insulated with gutta-percha.

The lead sheathing is drawn on cold at an enormous pressure, and squeezes the fibre insulation into a solid mass. The two coatings of lead afford greater security against a small imperfection than could be obtained by a single coating with the same weight of metal.

When the cables are laid in an iron troughing, the iron sheathing is dispensed with, and the pilot wires are laid separately.

Wires inside a building must be efficiently protected to avoid damage or accident, as well as to maintain the insulation. A good plan is to run the wires along parallel grooves in a wood casing, as it is usually stipulated that the coverings of the two conductors should always be separated by an independent solid insulating substance. When it is necessary for one wire to cross another, a slip of wood is interposed. The casing can be made in a variety of forms, and if necessary can match the beading or cornice.

India rubber covered with braided cotton forms about the best material for insulation for indoor work. Gutta-percha, for the reasons already enumerated, is less suitable, although its life can be considerably lengthened by protecting it from the atmosphere, which can be accomplished by carefully covering it with tarred tape.

We have already described certain pieces of measuring apparatus, but there are a number of other internal fittings which now claim attention.

The switch is a piece of apparatus which is in constant use, and for a variety of purposes, but chiefly to form a ready and expeditious means of making and breaking a circuit. The extension of the electric light has engendered a considerable development in the constructional details of such instruments, but in almost all cases the same general objects have been kept well in view. The forms of switch in use prior to 1878, from which time the revival

of electric lighting may be said to date, are altogether inadequate for present purposes, mainly on account of the large currents which they are required to carry, and the high potential differences which may exist between the different portions of the apparatus.

In order that a switch may be capable of efficiently performing its functions, its metallic parts must be sufficiently massive to carry the required current without heating or offering any appreciable resistance; the contact surfaces must for similar reasons be extensive; the moving contact piece must press firmly on to the fixed one; and simple striking contacts must give place to rubbing contacts, to avoid partial insulation through accumulation of dust and metallic oxide films. The circuit should not, when otherwise practicable, be completed through the axle upon which the rotating arm travels, unless a good independent rubbing contact between the axle and the bearing is provided, as dirt, oxide, &c., are liable to accumulate at the bearing surfaces, and in time impair the efficiency of the switch.

The switch should be so constructed that there is the minimum abrasion and wearing compatible with good and certain contact, and such parts as do wear away should be easily adjustable or cheaply renewable, so as to permit the re-establishment of good contact. In all cases, but more especially for currents of high E.M.F., the lever should be provided with a handle of insulating material. The terminals should never be so placed that in turning the handle there is any chance of the instrument being short-circuited by the operator's hand. When contact is broken the current (especially if the circuit contains any apparatus having considerable self induction) sparks across the air space in the effort to continue its course, volatilising a portion of the metal surfaces. After such an 'arc' has been once established its maintenance is not a matter of great difficulty; and it is evident that such an arc is quite competent to start a serious fire, besides in any case damaging the switch contacts. It is advisable to provide a snap action, so that the lever is set decidedly either on or off the fixed contact, the spring being so arranged that the lever is jerked quite away when it is turned almost out of contact. The actual sparking can in a great measure be prevented by causing the contact to be broken gradually instead of suddenly. The

movable contact can be made to quickly travel over a set of fixed contacts, throwing more resistance in circuit at each step, until the current has become so low that it is incompetent to cause a serious spark. Such a device need only be used in special cases. The contact surfaces can easily be protected by arranging two carbon rods, placed end to end, as a shunt, and allowing the contact between the two carbons to be broken just after that between the metallic surfaces. The sparking then occurs at the carbon surfaces, and the rods can easily be renewed when necessary. The base of the instrument should be of some good insulating material, not liable to warping or appreciable expansion or contraction. Wood should therefore be used with caution.

What is required is a material which is non-inflammable, a good insulator, does not readily condense moisture, or facilitate the accumulation of dust and dirt. Slate is a good material if free from impurities, such as mineral streaks or veins; glazed porcelain condenses moisture freely, and is brittle, the latter objection also applying to serpentine.

With these introductory remarks we can describe a few of the various forms of switch now in use. The 'ring' contact switch (fig. 296) is undoubtedly one of the best for carrying heavy

FIG. 296.

currents. It is mounted on a slate base, each terminal clip consisting of a number of split brass rings placed inside one another, the contact being made by forcing the connecting bar into the gap

e rings. This bar, which is a strip of stout brass with, in the cular form illustrated, the ends bent round, is provided with tantial wooden handles. As the contact surfaces wear away, gap can be reduced by tightening up the bolt which it will be passes across the vertical diameter of the rings. Lugs cast o the under side of the outer rings extend beyond the base, are bolted to terminals underneath, or to tubular holders which the main wires can be soldered. It will be seen that form of switch practically answers every requirement, the st possible connection being obtained, and the contact sur-s being self-cleaning. It is made to carry currents up to o amperes.

Messrs. Woodhouse & Rawson also make an excellent form of ch, shown in fig. 297. The switch bar consists of a number

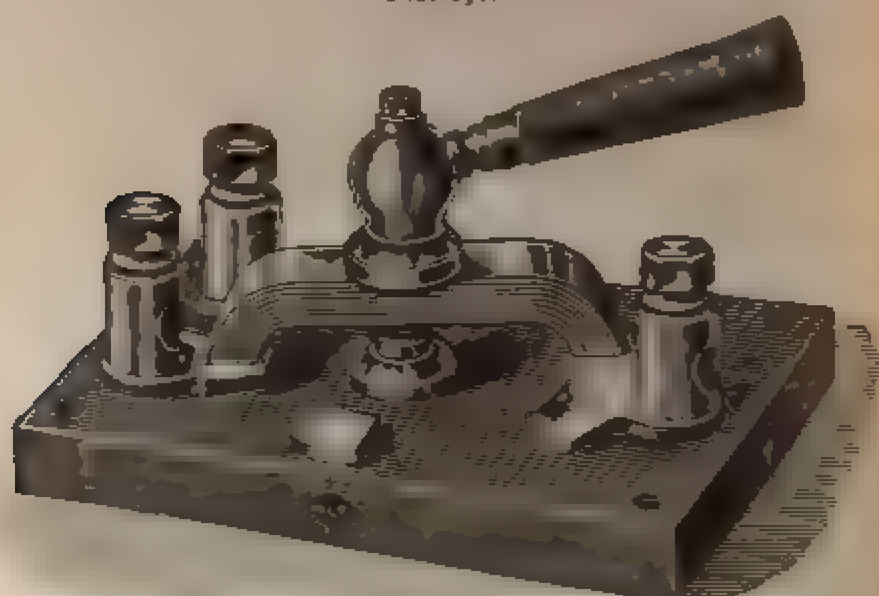
Fig. 297

in this case four bent strips of hard brass, which rub on to d blocks of a similar material. The edges of these blocks are

bevelled, to prevent the bar jarring against them, and at the same time to allow it to slide fully on to them, although the pressure is considerable. The switch has a quick break, almost instantaneous, owing to the action of a bent spring, which is compounded of four steel wires, as shown in the figure. This spring presses against a projection from the axle, which is edge-on when the switch is in the position shown, but which with a small movement is presented obliquely to the spring, allowing the latter to jerk the arm away clear of the contact blocks. These switches are provided with metal covers which are fixed by a bayonet joint.

Fig. 298 shows a modification which is made to carry up to

FIG. 298.

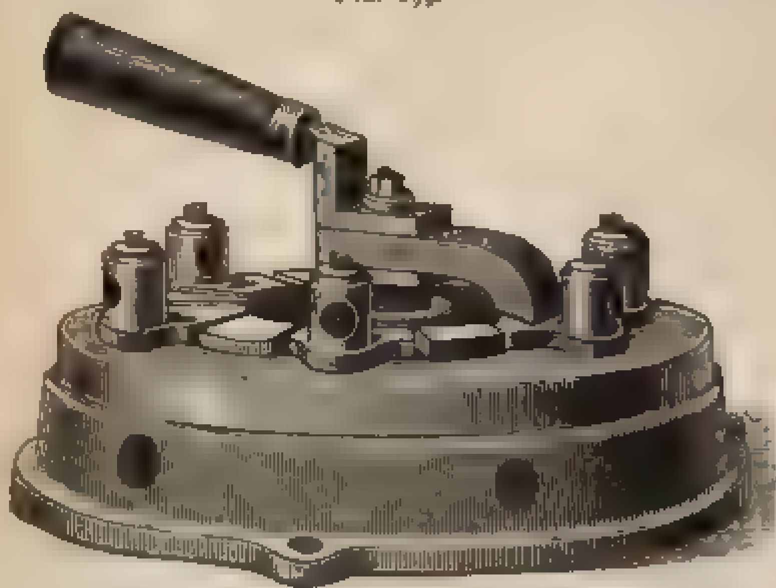


500 amperes. The contact arm or bar is made of several brass strips the extremities of which move over stout contact plates fixed to the slate base. This is a 'three-way' switch, the contact block, shown under the handle, being sufficiently large to allow the arm to complete the circuit from it to one or other of the two blocks near the opposite end of the arm. The circuit can also be completely disconnected, in which case the arm should be made to rest, in the intermediate position, on a pair of small plates, one of which can be seen in the front of the figure.

Fig. 299 illustrates a somewhat similar switch for enabling extra secondary cells to be placed in or out of circuit, one by one, during charge or discharge, as the arm is made to rotate. The

short circuiting of a cell is prevented by a coil of wire of suitable resistance mounted on a vulcanised fibre frame below the slate base, the whole switch being fixed on a hollow cast-iron frame,

FIG. 299.



perforated in several places to allow a free current of air to pass through it.

Another very useful form of switch is that in which the movable arm consists wholly or in part of thin flexible copper strips, screwed firmly into square tubes or sockets, and rubbing edgeways over solid brass or copper blocks. In one such switch the arm consists of a stiff flat spring terminating in square holders, in which the flexible brushes, composed of a great number of strips, are held by set screws. This type has the advantage that there is always an extensive contact surface, that adjustment is easy, that the brushes are comparatively inexpensive, and that they can be readily removed for cleaning or renewal.

In another switch of this type the arm consists of a large bundle of long flexible copper strips, passed through a rectangular hole in the axle and fixed firmly in position by screws. In this case the brushes rub against the inner vertical faces of the fixed blocks, instead of over the upper horizontal surface.

A switch of some kind is required in connection with every incandescent lamp or group of lamps, and of this class there is a vast number in use, many of them being simple forms of those

already described. Fig. 300 shows one made by Messrs. F[illegible], Lancaster & Co., in which the wires are connected to a pair of brass blocks which in their turn are connected to two flat springs, whose free ends ride over projections on the movable ebonite bar A B. Each of these projections consists of two studs, one being a non conductor and the other brass. In the diagram the flat springs rest on the two insulating studs, but on pushing A B inwards towards the left, the springs ride over and make contact with the brass studs, which being but the ends of a short brass rod passing through A B, complete the circuit of the lamp.

Fig. 300.

Fig. 301.

Fig. 301 illustrates a class of switch known as a wall socket, which is useful in cases where it is required to place a movable lamp in circuit at one or other of a number of positions, in such places as cellars, workshops, libraries, ship's bunkers, etc. The leads are joined to a pair of terminals in the lower block, which is permanently fixed in position. The upper or movable block carries the lamp, the terminals of which are connected to two split spring plugs, which can be pushed into the socket piece and so complete the circuit through the lamp.

Highly important as switches undoubtedly are in an electric light circuit, cut outs can scarcely be said to be less so. The function of a cut out is primarily to prevent damage being done to the apparatus, the leads, or the building in which they are placed, by means of an unduly strong current; and the way in which it

ds this protection is by automatically disconnecting the circuit n the current from some cause, accidental or otherwise, exs a certain pre-determined limit.

There may be said to be two species of cut-outs, (*a*) those ated by an electro-magnet, and (*b*) those consisting of a piece wire or foil which melts or fuses with a current of definite ength.

A magnetic cut-out consists essentially of a coil of wire placed the main circuit and provided with a movable core, or armature, which is attached a strip of metal also forming a part of the main cuit. When the current rises above the prescribed strength, e coil attracts its core or armature with sufficient force to draw ay the strip and break the main circuit. But it is necessary for e contact made by the strip with the ends of the main circuit to very good and also frictionless, otherwise the pull required to reak contact would be liable to vary. In the best instruments he two ends of the main circuit terminate in cups which are partly lled with mercury. A horse-shoe shaped copper rod is attached at ts centre to the armature, and each leg dips into one of the mercury cups. The contact is thus reliable, but there is a chance of serious sparking occurring at the mercury surface when the contact is broken with a heavy current, especially if any large electro-magnet having considerable self induction is included in the circuit. The advantages of such a cut out are, that it can readily be adjusted to act with certainty with any given current, either by varying the tension of an antagonistic spring, or by altering the centre of gravity of the moving piece. It can also be arranged to automatically restore the connection when the current falls again to a safe value. Although this latter arrangement is not as a rule adopted, the apparatus can be immediately restored to its normal state by hand, when the cause of the rise in the current has been discovered and removed. It is manifest that the resistance of the apparatus must be kept extremely low to avoid serious loss of power. It requires a certain amount of attention and is expensive compared with the type next to be considered, viz. the simple fuse.

A fuse can be constructed so as to offer very little resistance and therefore to absorb but little power. It must of course offer some resistance, since it is owing to the heat developed by

the current in overcoming this resistance that the fuse is melted. Obviously a fuse made of a metal which has a low melting point requires comparatively little electrical energy to raise it to a state of fusion; and hence a fuse composed of such a metal may be made of lower resistance, and so absorb less power, than if a metal with a high melting point (such as platinum, 2,000° C.) were employed. In fact, with a well-designed fuse the chief cause of loss of power is likely to be in the careless connection of its extremities to the terminals of the main circuit.

Such a cut out has no working parts likely to get out of order or to need any attention, is very inexpensive, and, if properly designed, can be relied upon to act when the current reaches any particular strength, or at any rate within about 5 per cent. of it.

The fuse must be designed so as to break promptly and certainly, and manifestly it should not, if it can possibly be avoided, be allowed to get red-hot, otherwise the danger from fire becomes serious. The lower the temperature at which the metal employed melts, the less is the danger thus incurred. It must not be forgotten that good conductors of electricity are also good conductors of heat, and that therefore the terminal screws to which the fuse is attached conduct the heat rapidly away. This fact necessitates the fuse being made rather longer than would otherwise be the case; and while the terminals must be sufficiently massive to allow good and reliable connection, they should not be unnecessarily so.

It is almost superfluous to add that the metal employed should be durable, and not subject to change from any cause such as oxidation. Platinum fulfils this condition admirably, and yet it is a most unsuitable material for general work on account of the high temperature at which it melts. It is, in fact, easy to maintain it at a bright red heat for a considerable length of time. Tin, however, melts at 235° C.; it is very durable, only slightly oxidisable, and, taking all things into consideration, is undoubtedly the best metal for a fuse.

The best work in this field has been performed by Mr. A. C. Cockburn, whose fuse is illustrated in fig. 302. The wire is of pure tin, a leaden shot is cast on at the middle of the wire, and its extremities terminate in small contact rings. These rings are slipped over the terminal screws, and the ...

g tightly screwed down reliable contact is ensured. The pce between the screws is such that the sag of the wire is t equal to that shown in the figure, and immediately the nt becomes strong enough to de- sufficient heat to soften the wire, weight of the leaden shot causes mpt and decided break. The dis- ection thus occurs long before the erature is reached at which the l would become red hot, and be- dry wood would ignite or even char.

Fig. 302.

cases in which these fuses are fixed are usually made of hard l, or of slate or porcelain for the base with a brass cover hed by a bayonet joint. In some instances a wooden case with asbestos and fitted with a glass cover is employed, the advantage being that the fuse can easily be inspected, so when a number are in use it can quickly be ascertained which ular one it is that requires to be renewed. The rings at the of the wire enable the replacement to be effected with ease rapidity, and they have the further advantage that they pre- any uncertainty as to the length of wire actually in use. the capacity of the terminal screws for conducting away eat affects the result, the fuse should only be employed in rticular type of case for it has been designed.

Fig. 303.

or heavy currents several aratively small fuses are d in parallel, instead of oying a massive wire, rangement which makes certain the breaking of uses when the particular nt strength is exceeded.

n fig. 303 is shown one e simple fuses placed in ion, the cover of the case being removed. The ends of the lead are brought up through holes in the slate base, one h of two fixed brass strips, the fuse itself being connected

to other terminal screws on the same strips. The case c
quired be placed horizontally.

Many other types of cut outs are in use, some con
wire, and others of thin foil of various metals, but that d
is probably the best for general work, and is sufficiently ine
to allow of one being placed in circuit with every inca
lamp in any installation.

An illustration of a method by which a cut out may be
to protect a single lamp is furnished by fig. 304, which

Fig. 304.

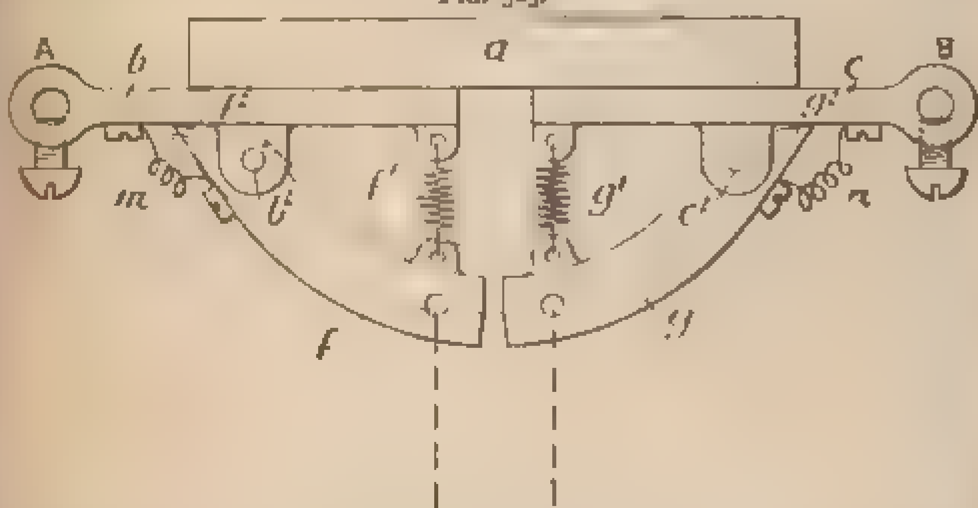
ceiling rose, or a device for placin
in circuit between a pair of lead
along a ceiling, and suspending
therefrom. The wires from th
enter through holes in the back
apparatus, and are connected ea
small brass block or strip, one of
also connected to one lamp termi
the other to one end of the safe
the other end of the fuse and th
terminal of the lamp are joined to
brass block. The flexible double
which the lamp is suspended is th
through a hole in the centre of the
which screws on to the base.

One possible objection to the
fuse is that when it does act un
influence of a too powerful curr
destroyed, breaks the circuit of th
or lamps, and must be replaced
the circuit is again available. It will be evident that su
outs must be cheap, placed in accessible situations, b
replaceable, and be confined in an infusible or non-infla
case.

The cut-outs which we have thus far described are f
as a safeguard against the maintenance of an excessive curre
as might be caused by the short circuiting of a lamp, and
more particularly applicable to constant potential, or
working. When, however, a series circuit is fitted up,

to be guarded against is rather a disconnection than a short circuit, for should the filament of a single lamp, or any one of the conducting wires be broken, the current through the others will also be interrupted. We have already described (in the preceding chapter) a few protecting devices for the lamps themselves, but none capable of affording protection in the case of a complete smash of a lamp have been dealt with. Mr A. A. Goldston has introduced a simple but ingenious contrivance for maintaining, under almost *all* circumstances, the continuity in a series circuit consisting of a number of suspended lamps. The device is illustrated in fig. 305, and is intended to short circuit the sus-

FIG. 305.



pending wires of any lamp in the event of one or both of those wires breaking, or if from any other cause the weight on either of the wires is reduced.

A and B are the two main terminals which are attached to the brass pieces f^2 g^2 which are fixed on the insulating base *a*. The conducting spirals *m n* serve to connect the screws *b c* to another pair of screws on the contact-making levers *f g*. These levers are able to turn through a small angle on the pins b^1 c^1 and are supported by the spiral springs f^1 g^1. The wires by which the lamp is suspended are attached one to *f* and the other to *g*, the weight of the lamp sufficing to keep *f* and *g* apart. Should one of the wires, say that attached to *f*, break, the tension is reduced, and the corresponding spring f^1 is allowed to act, drawing *f* into the position indicated by the dotted lines and completing the

circuit through the two pivoted levers direct. The device is applied to arc lamps, and can be fitted in incandescent l holders so as to maintain the circuit in the event of a disco tion at the platinum loops or in any portion of the holder. spiral springs are in the actual apparatus provided with adj screws, by which their tension can be regulated so that were the bulb broken this slight reduction of the weight would the springs to raise the levers. The arrangement effec provides also for the case of a complete smash of the l such as might destroy the short circuiting device inside lamp itself. Under ordinary circumstances a short-circuit twee , or a fracture of either of, the suspending wires m initiate an arc, which would then probably travel up the and possibly start a fire. The device under notice pre the maintenance of such an arc, because immediately the is fused and the weight removed the two conductors are out of circuit.

The apparatus is made in a variety of forms, but an adva pertaining to the one illustrated is that the contact surfaces b vertical do not permit the accumulation of dust or dirt. potential difference available in a series circuit is, however, cient to strike across even a considerable film of imperfectly ducting particles. It will be evident that to make this app most efficient, it is better to use two separate instead of tw conductors.

In a previous chapter we have described certain instru called ammeters, which are capable of indicating the numb amperes of current flowing through them at any particular mo but which are unable to measure the actual quantity of elec passed through them during any given time. In just the way a thermometer indicates the temperature at any moment gives no idea of the quantity of heat actually developed or sorbed. In the commercial distribution of electricity for ligh or other purposes, it is essential that a 'meter' should be pro which is capable of measuring and by some means recording quantity of electricity supplied to any one consumer during a month or three months. The unit quantity of electricity i coulomb, that is the amount transferred by a current

ampere during one second; hence an instrument such as that referred to might aptly be called a coulomb-meter.

The coulomb is, however, too small for electric lighting work, and it has been usual to employ as a unit the quantity of electricity transferred by a current, one ampere in strength, during one hour, this unit being known as the 'ampere-hour.' If, for example, a secondary cell were allowed to maintain a current of 15 amperes for $2\frac{1}{2}$ hours, the *quantity* of electricity obtained from the cell during that time would be $15 \times 2{\cdot}5 = 37{\cdot}5$ ampere-hours. But even this larger unit is somewhat small for the measurement of supply on an extensive scale. We have already mentioned the kilowatt as the practical unit of power, sometimes referred to as the Board of Trade unit of power. The Board of Trade unit, properly so-called, is a commercial unit of electrical energy, and is equal to that amount which is developed or absorbed by a current of 1,000 amperes at a pressure of one volt during one hour. It is therefore equal to 1,000 ampere volt-hours.

This Board of Trade unit is, then, the unit by which the electricity supplied is measured and charged. Under ordinary circumstances some piece of apparatus is introduced to indicate the number of ampere hours supplied to the consumer's lamps, and this quantity multiplied by the pressure in volts and divided by 1,000 gives the number of Board of Trade units upon which the charge is based. But it is unfortunately far from easy to measure a quantity of electricity satisfactorily on a commercial scale. In fact the instrument most urgently needed in the electrical world at the present moment is a simple, reliable, and compact quantity meter.

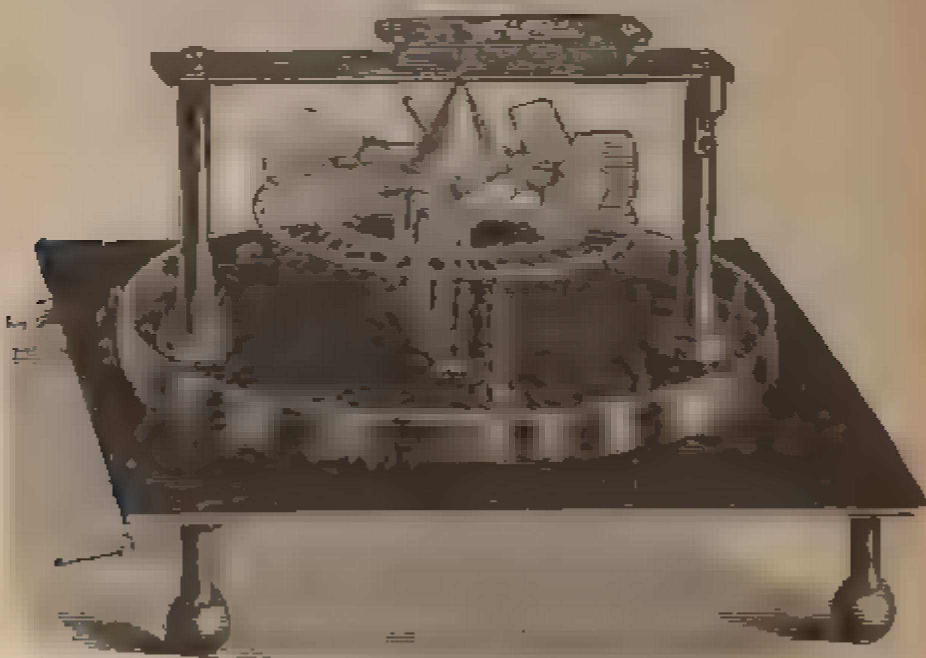
Many efforts have been made to produce such an instrument, and although some practical forms have been brought into use, much yet remains to be done by the usual process of development.

The simplest in principle, and perhaps also the most interesting, is that devised by Professor Forbes. It is based upon the heating effect of the current; the instrument can therefore be made without any appreciable self-induction, and is consequently available for use with alternating currents.

The apparatus is illustrated in fig. 306. It consists of two

concentric copper rings, supported at a little distance above the base and bridged across by a number of short fine wires. The current enters at one ring and leaves it by the other, passing through the whole of the fine wires in parallel, the resistance offered by the wires being about $\frac{1}{100}$th of an ohm. The quantity

FIG. [illegible]



of heat developed in these wires affords the means of estimating the quantity of electricity which passes. When the wires become warm the heat is imparted to the adjacent air, which expands and rises, so that a continual upward current of air is maintained during the whole time that the current is flowing, the strength of the air-current varying of course with the extent to which the wires are heated. A small pillar carrying a steel needle point rises through the centre of the rings, and a thin paper cone with a ruby bearing at its apex rests on the needle point. The base of the paper cone is attached to a small horizontal mica disc, from the edge of which project eight arms made of pith, each carrying a very thin mica vane, inclined at an angle of 45° to the horizontal, and placed directly over the fine cross wires.

The ascending air currents caused by the passage of electricity strike against the under side of the vanes, and cause them and the paper cone to rotate, the stronger the current of electricity, the

more powerful are the air currents and the greater the number of revolutions in a given time. So that it is only necessary to add some device for recording the number of revolutions in order to estimate the quantity of current which has flowed.

The apex of the paper cone consists of a small aluminium cone (to which is attached the ruby bearing above referred to) and which also carries above the apex a small steel pinion, gearing into a train of wheels as shown in the figure. The train records the number of revolutions in the ordinary manner; but it will readily be apparent that since the force which causes the rotation is so feeble, the slightest friction would be inadmissible, and the whole of the moving parts must be extremely light and delicate. In fact, beautiful as the principle is, it is to be feared that it would be difficult to develop it into a thoroughly practical instrument.

A quantity meter also based upon an interesting principle, and which in spite of many difficulties is being brought into a practical form, is that of Mr. Ferranti. We know that a conductor when placed in a certain position in a magnetic field is urged to a new position in, or entirely out of, the field, immediately a current is passed through the conductor. If any portion of the conductor is movable independently of the remainder, we can move that portion only by sending all or nearly all of the current through it. A somewhat striking case is that of a liquid conductor such as acidulated water or mercury, for we can keep the liquid continually in motion by placing the containing vessel in a powerful field, and sending a current through the liquid. If the lines of force of the field and those emanating from that portion of the liquid which is carrying the current do not happen to coincide, then that portion will be urged to a new position just as a copper wire would be, its place being taken by more of the liquid, which undergoes a similar treatment.

In Mr. Ferranti's meter, which is based upon this principle, the liquid employed is the purest obtainable mercury. This is contained in a rather shallow circular vessel, above which is placed a solenoid fitted with a hollow iron core and a sheath, so disposed as to project a very powerful field vertically through the mercury. The current is led to the mercury at the centre of the vessel, and

leaves it at the circumference, then passing through the magnetising solenoid.

Now the liquid conductor is urged to move in a direction at right angles to that in which the current is flowing through it, and also at right angles to the lines of force of the field. The direction of the current is radial, and supposing the lines of force to be projected vertically downward, the liquid will rotate in a right-handed direction as viewed from above. The force with which the mercury is urged to rotate is proportional to the strength of the current flowing through it and to the strength of the fixed field. This field might be kept constant; or by employing the same current to excite the solenoid, and never allowing the iron to approach the saturation point, the field may be made to vary with the current, when the force tending to produce rotation will be proportional to the square of the current.

The mercury in rotating carries with it a light delicate float which is attached to the lower end of a light rod terminating at its upper extremity in a pinion which gears into a wheel forming part of the mechanism employed to indicate the number of revolutions made by the float. Of course the force acting is very small, and any appreciable friction would seriously affect the indications, but it appears probable that the difficulties will be overcome and the instrument brought into practical use.

The meter which, up to the present, has been most extensively employed is based upon the electrolytic properties of the current, and possesses the advantage that no delicate mechanism need be employed in connection with it. When a current is passed through a solution containing a metal, such as nitrate of silver or sulphate of copper, the solution is decomposed and the metal which it contained is deposited on the wire or strip of metal by which the current *leaves* the liquid. Such a wire or strip by which the current leaves or enters the liquid is called an electrode. Suppose, for example, a solution of nitrate of silver with silver electrodes to be employed, then pure silver would be deposited from the solution upon that electrode by which the current leaves. Moreover, an exactly equal quantity of silver would be dissolved from the other electrode; this might easily be proved by weighing before and after the passage of a current, for it would be found that the

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[illegible] than the quantity of [illegible] would be [illegible]

The [illegible] meter [illegible] is constructed upon the [illegible]

The [illegible] the passage of the current [illegible] in an ordinary [illegible] would have to be [illegible] as a shunt [illegible] a resistance equal to [illegible] In this case the meter measures [illegible] of the [illegible]

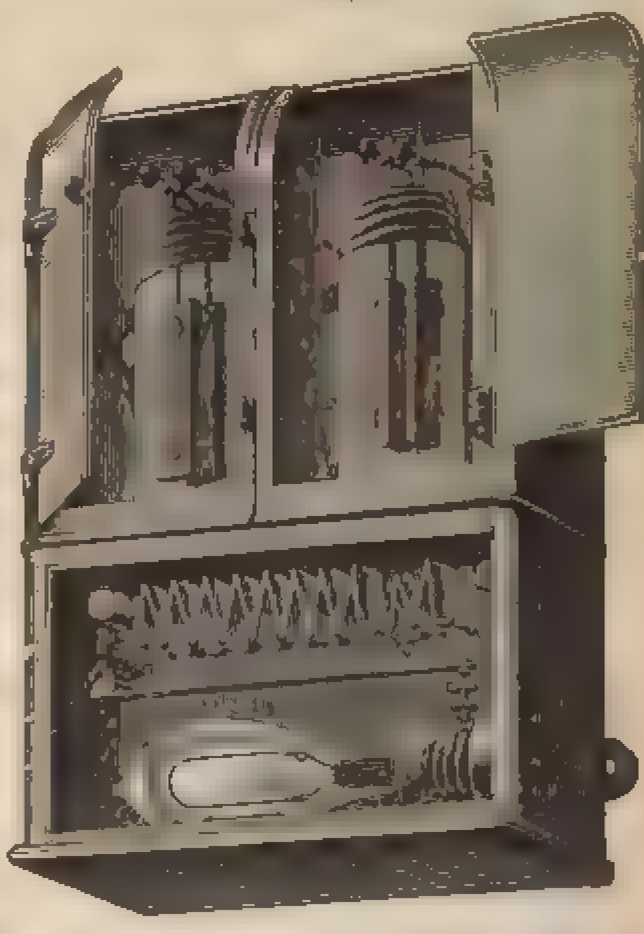
But [illegible] temperature variations alter the resistances sufficiently to cause grave errors in the results. A rise in temperature, for instance, reduces the resistance of the liquid, but increases that of the portion of the main conductor which is shunted by the cell. Both these effects tend to cause an increase in the proportion of the current flowing through the meter, and such variations must in some way be compensated for.

Moreover, the temperature may fall low enough to freeze the liquid. As [illegible] an external [illegible] which [illegible] the [illegible] the shunted [illegible] conductor, or both, makes the meter register lower than it should do, care must be taken to so place these parts as to avoid leading the consumer into temptation. For such

reasons the terminals of a meter should never be exposed, nor any other facilities given for short-circuiting the apparatus.

The practical form of the Edison meter, as fitted for use in a simple circuit, and in which these difficulties are overcome, is illustrated in fig. 307. At the bottom of the case is an incandescent lamp, which is automatically thrown into circuit whenever the temperature approaches the freezing point, and so keeps the solution from freezing. Above the lamp is placed a stout zigzag strip of German silver, which is joined up in the main circuit. It offers but little resistance, and since its temperature coefficient is small, this resistance varies but slightly through ordinary changes. Above this strip two cells are placed, each containing two zinc plates immersed in a sulphate of zinc solution. The zinc is deposited at a definitely faster rate in one cell than in the other, and an additional check obtained by comparison of the two cells. The difference in the rate of deposition is effected by causing one cell to bridge a larger portion of the German silver strip than the other; the dividing terminal is seen in the figure at the end of the second bend from the right. The most important of the possible sources of error is that due to the temperature variation of the resistance of the liquid. This is compensated for and the resistance of the cell circuit kept constant in a very simple manner. When the temperature rises the resistance of the liquid *decreases*, but the resistance *of a metal* (copper for instance) *increases*. A spiral of copper

FIG. 307.



wire is placed in series with each cell, of such a resistance that with a given rise in temperature the resistance of the spiral increases by just so much as the resistance of the liquid is decreased. These spirals are placed behind the cells and are not visible in the figure.

In the smaller meters (and latterly in larger ones) only one cell is employed, the resistance of the German silver strip being about [illegible] ohm.

The meter is placed in the circuit of one of the mains feeding the group of lamps in which the electricity consumed is required to be measured.

For installations on the three-wire system two separate German silver strips with a cell or a pair of cells to each are provided, one strip being placed in each main.

The variation of the resistance of the German silver strip caused by temperature changes is not sufficient to introduce any great error. As a rule its resistance is $\frac{1}{999}$ that of the cells and compensating wire, so that the cell measures $\frac{1}{1000}$ of the total current passing through the main circuit. The plates are weighed once a month.

The method of throwing the heating lamp in circuit when the temperature falls too low is simple and ingenious. One terminal of the lamp is connected to one of the mains, and its other to a small contact stud placed just above the holder. Above this stud is another contact carried at the end of a long straight compound metal strip, which is fixed at the other end (to the left in the figure) and connected to the other main. The strip is formed of two metals, which expand or contract unequally when the temperature is varied. Under ordinary circumstances the two contact studs are kept apart; but when the temperature falls the compound strip bends or curls downward, and the adjustment is such that contact is made and the lamp thrown in circuit when the temperature approaches within two or three degrees of freezing point.

INDEX

[Every dash ( ) stands for a word in the line preceding it.]

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